100 COSMOS THE SCIENCE OF EVERYTHING

COSMOS

ISSUE 100

THE SCIENCE OF EVERYTHING

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Hitchhiker's guide to the future

SCIENCE vs SUPERBUGS
Research making resistance futile

REASONS TO HOPE

REALITY BITES
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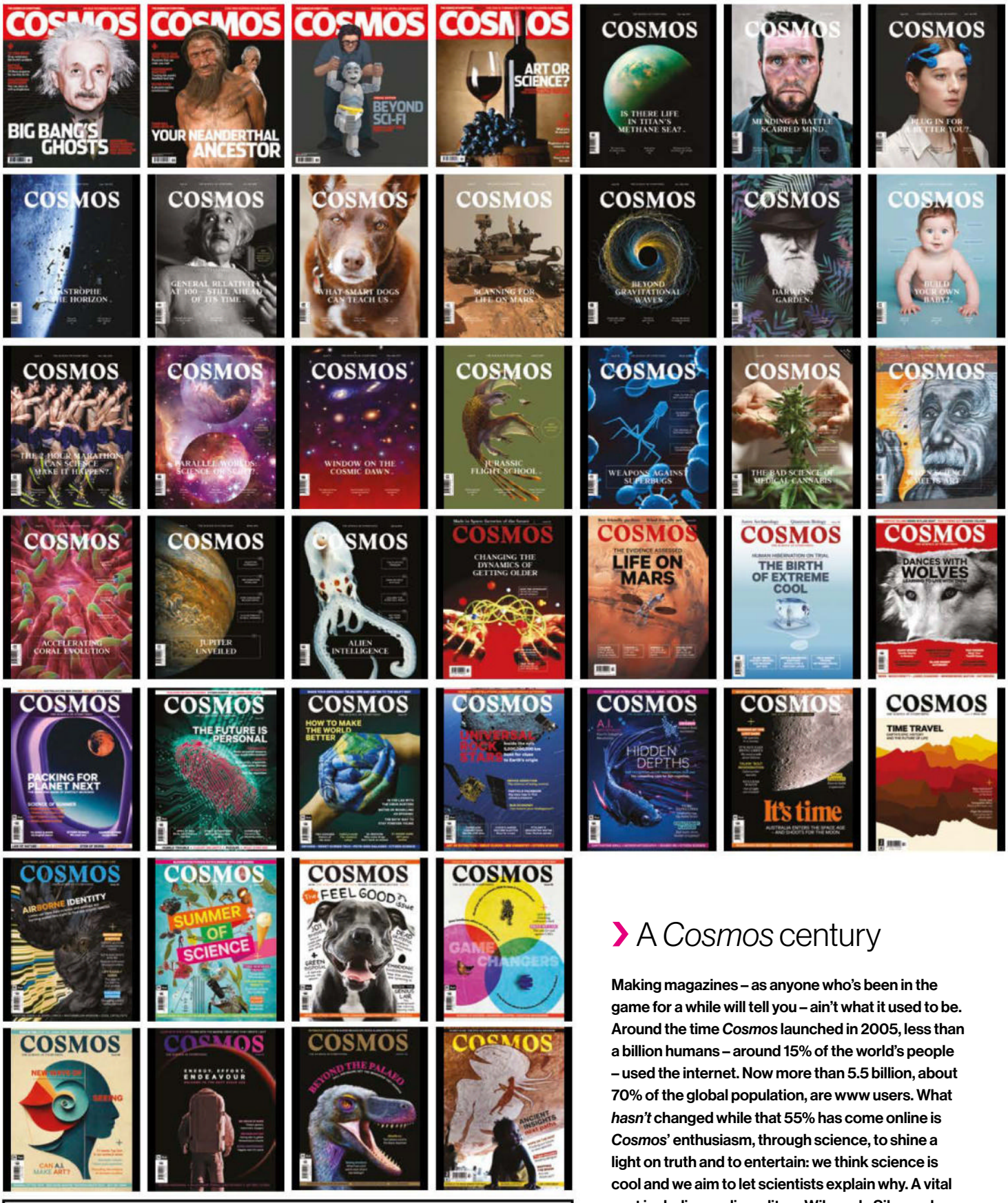

Issue **100**

› A *Cosmos* century

Making magazines – as anyone who's been in the game for a while will tell you – ain't what it used to be. Around the time *Cosmos* launched in 2005, less than a billion humans – around 15% of the world's people – used the internet. Now more than 5.5 billion, about 70% of the global population, are www users. What *hasn't* changed while that 55% has come online is *Cosmos*' enthusiasm, through science, to shine a light on truth and to entertain: we think science is cool and we aim to let scientists explain why. A vital cast including earlier editors Wilson da Silva and Elizabeth Finkel set this tone; others have followed with their own science personas and plans. What's next? Hopefully we bear witness to science leading the world through what will likely be its era of greatest need for evidence-based knowledge and truth. We listen, learn, act – and remain hopeful.

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I WELCOME YOU to the 100th edition of *Cosmos* magazine.

Cosmos's print and digital editions form one of the important pillars of our mission. That, simply, is to change the relationship that all Australians have with science. *Cosmos* works in harness with the Royal Institution of Australia's education platform and our public outreach activities to fulfill this mission, of which it's an essential part.

Thoughtfully considered and patiently and accurately curated, the magazine's long-form articles represent the best of science journalism; they allow our readers to deeply engage a broad selection of scientific discovery, and through this, to engender both a sense of comfort and wonder in the work of science.

Cosmos editor Gail MacCallum has chosen "Reasons to Hope" as the 100th edition's theme. I think science gives us many reasons to hope – but we inhabit a world where digital platforms publish content with little oversight and no sense of the truth's valency. The avalanche of 'information' they create is either the work of the uninformed or – more troubling – those determined to sow uncertainty among us.

Science, at its best, underpins the certainty and reality that we need to advance. It gives us a view of our universe that illuminates wondrous truth, and dismisses all that's trivial, petty – or just plain untrue.

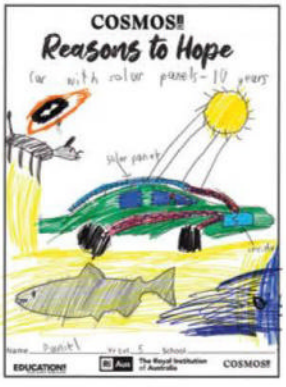
In our current information and media landscape, *Cosmos* is as precious as a rare gem. It's the last long-form science magazine in Australia. That makes it a bastion of fact in the face of an avalanche of misinformation.

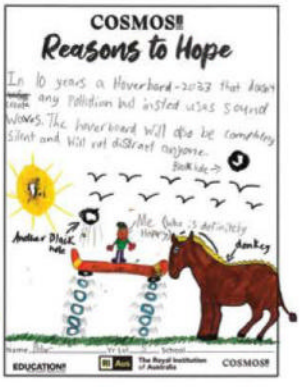
The Royal Institution of Australia cannot lay claim to creating *Cosmos*: that was the innovative work of others. The publication was gifted to us in 2018 by Elizabeth and Alan Finkel, who both remain supporters of and contributors to our work today.

We are custodians of *Cosmos* in that same way that scientists are the custodians of centuries of scientific discovery. Over the past five years, we've leveraged advances in technology and new ways in which audience engage with content to expand the publication in all of its currently potential forms – digital, audio and video. Our aim, always, is to reach more people with those reasons to hope that science brings.

I know you'll enjoy this 100th edition. And I thank you for your ongoing support of *Cosmos* and the Royal Institution of Australia.

PETER YATES Chairman
The Royal Institution of Australia





Our art director, Kate, loved these cover suggestions from some Adelaide primary school students. We'd also love to hear scientific developments you're hopeful about and read or see other reasons to hope:

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The Royal Institution of Australia is an independent charity dedicated to connecting people with the world of science. Through *Cosmos* magazine, our free daily science news site cosmosmagazine.com, our international science film festival SCINEMA and free educational resources, we aim to be an inspirational resource centre for the wonders and achievements of Australian and the world's scientific discoveries. We want to spark in all people a desire to be science literate and to make informed decisions about their lives based on rigorously sought and tested evidence.

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From the Editors

"HOPE," WROTE POET Emily Dickinson, "is the thing with feathers / That perches in the soul / And sings the tune without the words / And never stops – at all." It's easy to argue now (Dickinson was writing in 1861) that there's less reason to celebrate hope – even that we're entering, or already living through, an era defined by its loss. But in an uncertain world, hope is a valuable commodity: something to be treasured and celebrated. It's also what scientists commit to every day – puzzling over problems, collecting information, inventing solutions and working towards a future for all of us that is healthier, smarter and more sustainable.

The past 20 years have seen extraordinary leaps forward in many areas: genetic sequencing, renewable energy technology, customised medicine, space exploration and conservation successes such as the humpback whale recovery, to name a few. They've also seen 100 issues of *Cosmos*, which has reported on these events and many more in its award-winning journalism and design.

To celebrate, we commissioned renowned perspective artist Jenny McCracken to create an artwork for the cover, showing her take on the excitement and hope that science offers. You can read more about Jenny in these pages, along with exploring the curiosity and effort scientists bring to their day jobs and the ways in which their work will change our lives in the decades to come. A paradigm shift in chemistry; the fight against the planet's superbugs; unexpected possibilities for resilience in conservation; and shifts in AI, technology and engineering, including a record-breaking Landcruiser with some DIY customisation that recently crossed Darwin Harbour – underwater. All are examples of Aussie ingenuity and optimism at their best.

And we'd love to know what you're hopeful about – by email, letter or even a cover mockup, as some next-generation readers and science enthusiasts have provided opposite. And one more excitement: we're delighted to welcome Lauren Fuge as our deputy editor. Lauren interned at RiAus a decade ago, and with *Cosmos* in 2017; since then she's been a journalist in our daily newsroom as well as feature writer for the magazine (one of her pieces – on geology and deep time – was the winner of last year's UNSW Press Bragg Prize for Science Writing).

What will the next 20 years bring? So many reasons to hope...

GAIL MacCALLUM Editor
IAN CONNELLAN RiAus Editor-in-Chief
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› Science news from around the globe (and even further)

DIGEST

The IceCube Lab, located near the South Pole, recently created a "photo" of our home galaxy – using not photons, but neutrinos.

MARTIN WOLF, ICECUBE/NSF

ASTRONOMY

IceCube scientists snap first neutrino "image" of the Milky Way

Machine learning produces the first particle portrait of our home galaxy.

DEEP UNDER the ice at the South Pole sits a telescope that captures ghost particles.

The telescope – called the IceCube Neutrino Observatory – has just analysed 10 years of data using new machine learning techniques and found evidence of neutrino emissions from the Milky Way.

They've even been able to create the first neutrino "image" of our Milky Way.

If this result pans out, it would provide scientists with a long-sought source of cosmic rays.

"As is so often the case, significant breakthroughs in science are enabled by advances in technology," says Denise Caldwell, from the US National Science Foundation.

"The capabilities provided by the highly sensitive IceCube detector, coupled with new data analysis tools, have given us an entirely new view of our galaxy – one that had only been hinted at before.

"As these capabilities continue to be refined, we can look forward to watching this picture emerge with ever-increasing resolution, potentially revealing hidden features of our galaxy."

Neutrinos are tricky particles to catch. They have high energy but no electrical charge and almost no mass. They travel at nearly the speed of light, and blip through whole planets without interacting with them.

But the saving grace is that there are a lot of them – trillions pass through our bodies every second.

One way to catch them is through large telescopes like the IceCube Neutrino Observatory – which is 2.5 km under the ice and can detect when neutrinos occasionally create charged particles.

But there's not just one type of neutrino either.

"Searches for astrophysical neutrino sources are affected by an overwhelming background of muons and neutrinos produced by cosmic ray interactions with Earth's atmosphere," the scientists write in their new paper.

"Atmospheric muons dominate this background; IceCube records about 100 million muons for every observed astrophysical neutrino."

Even worse, cosmic rays produced within the Milky Way arrive from random directions, meaning that it's incredibly difficult to confirm where exactly they are coming from.

However, after using IceCube's 10 years of data and a new machine learning model, the team found neutrino emissions from the Milky Way's galactic plane at a 4.5 sigma level of certainty.

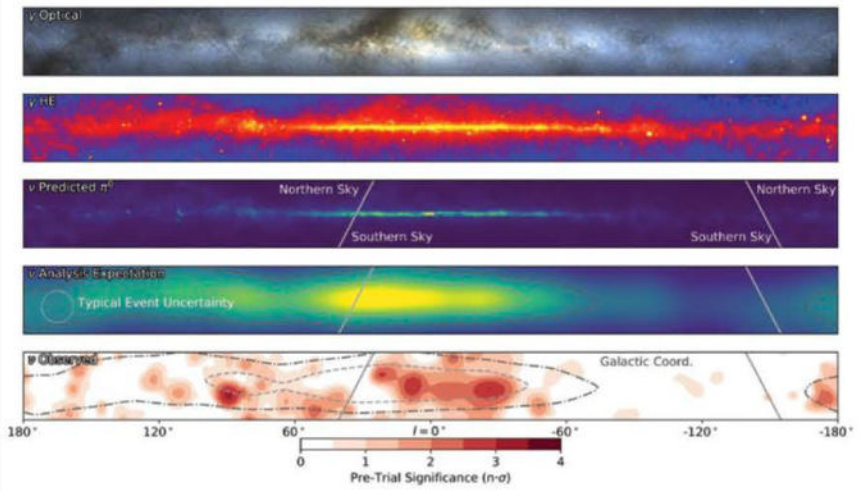
The scientists will need to get up to sigma 10 to confirm the findings. And although they know it's coming from the Milky Way, they also don't have exact positions of where in the galaxy it's coming from – that's the next step.

"Observing our own galaxy for the first time using particles instead of light is a huge step," says Naoko Kurahashi Neilson, professor of physics at Drexel University in Philadelphia, US, and a member of the IceCube team.

"As neutrino astronomy evolves, we will get a new lens with which to observe the universe."

The research is published in *Science*.

Multi-messenger portraits of home



These images, centred on the Milky Way's heart, show the entire galactic plane in light (optical, gamma rays) and in particles (neutrinos – both predictions and actual observations).

ICECUBE

MEDICINE

More than a game: puzzles may reduce dementia risk

Playing games, doing crosswords, writing letters or learning something new are all associated with reduced dementia risk, according to a large, long-term study, published in *JAMA Network Open*.

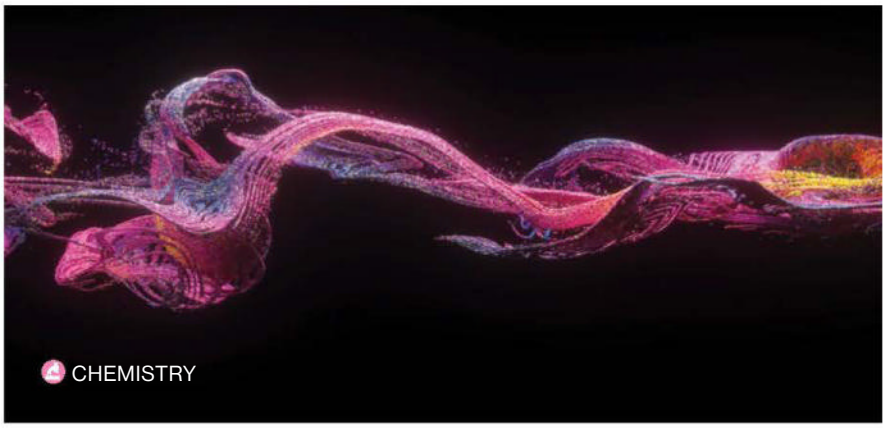
The study tracked 10,318 Australians with a median age of 73.8 from 2010 to 2020, collecting detailed information on the types of leisure activities they engaged in, along with regular health checks and cognitive assessments.

Writing, using a computer or taking education classes were associated with an 11% lower risk, while activities like playing games or doing puzzles were associated with a 9% lower risk.

Social activities were not associated with dementia risk, possibly because participants were broadly already socially engaged.

Co-author Joanne Ryan from Monash University says "the findings show that engaging in mentally stimulating activities can help preserve cognitive function and may help delay the onset of dementia".

ANDRIY ONUFRIYENKO / GETTY IMAGES



CHEMISTRY

Droplets that can spot cancer and improve DNA testing

Welcome to the new field of micro elastofluidics.

FLUIDS BEHAVE differently at microscopic and nanoscopic levels. If their behaviour can be manipulated, they could be used to deliver medicines to the body, spot diseases, and grow cells that become vital medical treatments.

That's the theory of Nam-Trung Nguyen, director of the Queensland Micro and Nanotechnology Centre at Griffith University, who spoke at the First Australian Conference on Green and Sustainable Chemistry and Engineering in July.

Nguyen first became interested in the field of micro elastofluidics after looking at wearable medical devices, which are mostly solid. Because liquids can be more flexible, devices made from them could be more effective at providing medical care.

Micro elastofluidics looks at how fluids flow in solid structures, at the scale of molecules and tiny devices. This means drops of fluids somewhere on the scale of micrometres to nanometres (or human hairs to molecules).

It also concerns things that happen within a fraction of a fraction of a second.

"With high speed, and short distance, you get a lot of energy," says Nguyen. "This energy can help your reaction happen faster."

So, what's the catch?

"The problem is, liquid is difficult to handle at the smaller scale," says Nguyen. "Liquid is formless: you cannot control it easily."

Nguyen and colleagues have figured out some ways to manage this.

One is to coat micrometre-sized drops of liquid with a solid, such as a gel, making liquid marbles. These tiny beads have a number of applications, including filling them with medicine for targeted drug delivery without needles.

"If I can make this type of small capsule micrometre-sized, and use kinetic energy to ballistically pierce the skin, I can deliver the same liquid into the skin without pain," says Nguyen.

They could also be used to grow and deliver stem cells to treat injuries, and make PCR testing – the best way to sequence DNA – more accurate, showing the concentration of DNA as well as its presence.

BIOLOGY

Tickled pink: neuroscientists tickle rats to find brain's play centre

Study pinpoints brain region linked to laughter and play.

SCIENTIFIC EXPERIMENTS are rarely amusing for rats, but new research by German neuroscientists involved tickling rats to investigate the brain mechanisms behind play.

The study, published in *Neuron*, identifies a specific part of the brain called the peri-aqueductal gray (PAG) as the driver of playfulness.

Co-author Michael Brecht from the Humboldt University of Berlin says that while play is critical for humans and many animals, the associated brain mechanisms are poorly understood.

"For example, we do not know why young animals and humans are very playful, whereas older individuals lose playfulness," he says.

In a series of experiments, scientists tickled rats, invited them to "chase the hand" and checked to see if the animals were having fun by listening for rat vocalisations.

When rats are enjoying themselves, they emit a high-pitched squeak at 50kHz, inaudible to humans.

"We chose rats because they are very playful and ticklish animals," Brecht says. "In this regard they differ from mice (the subject of most cellular neuroscience) that are not very playful or ticklish."

During the experiments the researchers used high resolution neuron recordings enabling them to measure activity in different subregions of the rats' brains.

"When we found cells in the lateral column of the PAG that responded very strongly to tickling and play, we had a first hint that we were recording a play-related structure," Brecht says.

The team compared rat vocalisations during tickling and game-play under relaxed conditions, and after blocking activity in the PAG brain region with an injection of muscimol (a psychoactive drug that can induce anxiety) and separately of lidocaine (a local anaesthetic).

"We later on did additional blocking experiments, where we blocked specifically the lateral column of the PAG (where we had observed many play-activated cells)," Brecht says.

As a result, the vocal responses to tickling and play in the rats was reduced.

PHYSICS

Physicists confirm existence of "demon" particle

A "DEMON" particle that has been haunting physicists for nearly 70 years has been found in an experiment by American researchers.

It is not a particle in the traditional sense like a proton or electron. It is a "composite" particle made up of a combination of electrons, in a solid.

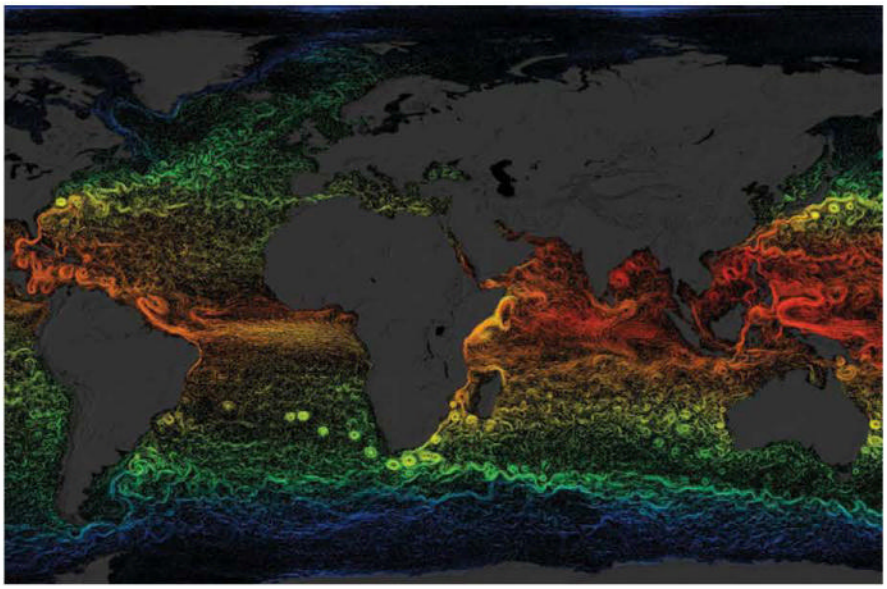
In 1956, theoretical physicist David Pines predicted that electrons in a solid could do something strange. Electrons have both mass and charge.

But Pines asserted that combinations of electrons in a solid could form a composite particle that is massless, has no charge and does not interact with light. He called this a "demon" particle.

Physicists have speculated that Pines's demon plays an important role in the characteristics of many metals. But they've never been able to confirm its existence until now.

The research from a team at the University of Illinois, Urbana-Champaign, is published in *Nature*.

JAGODA MATEJCZUK / GETTY IMAGES



Visualisation of global ocean currents, of which AMOC is one.

NASA GODDARD SPACE FLIGHT CENTER

CLIMATE

Next tipping point? Atlantic circulation could stop this century

Ocean current system collapse will affect us all.

DANISH RESEARCHERS have calculated an essential ocean circulation process could grind to a halt mid this century, pushing the Earth closer to an irreversible climate tipping point.

Peter and Susanne Ditlevsen – a brother-sister duo at the University of Copenhagen in Denmark – collaborated on an analysis of statistical early warning signals to estimate that the Atlantic Meridional Overturning Circulation (AMOC) will collapse in the next 65 years.

AMOC is one of the planet's major ocean mixing processes, often described as a conveyor belt that relays cold salt water from the North Atlantic towards the South Atlantic while simultaneously dragging warm water from the south to the north. This process results in the cooling of warm water near the poles to aid sea ice formation. In turn, residual salt left out of this freezing process causes the surrounding water to become dense and sink to the depths of the ocean where it joins the conveyor belt.

But global warming due to industrial greenhouse gas emissions has changed this dynamic, as melting sea ice dilutes the dense saline bottom water. That's a problem, because the conveyor process also brings cold water to the surface over time, dragging nutrients from the sea floor and providing a foundation for many marine ecosystems. If the AMOC stopped, these vital processes would be severely impacted.

It's been known for some time that the AMOC is probably slowing, but even the most recent reports from the Intergovernmental Panel on Climate Change estimated such a process wouldn't eventuate until next century. Now, the Ditlevsens' research forecasts this circulation will collapse sometime in the next 65 years.

The AMOC is considered a climate tipping point connected to the loss of ice in the Arctic and Greenland and influencing the same in Antarctica. This could form part of a cascade effect which leads to other of these climate safeguards being breached.

The Ditlevsens' modelling of the AMOC collapse draws on 150 years of Atlantic sea surface temperatures from 1870 to 2020, as a 'fingerprint' for the process. With AMOC tracked continuously from 2004, the use of proxy temperatures dating to pre-industrial times gave the pair a "baseline, pre-climate change" to assess.

"That's exactly what enables us to say that, well, now we're starting to push towards the bifurcation point, a tipping point," says Peter Ditlevsen, who is a physicist and climate researcher.

Previous studies have found early warnings for instabilities in the AMOC.

"But what was not established and could not be established was, how significant are these findings, and when was it going to happen?" says Peter Ditlevsen.

Now, Peter and Susanne – a professor in statistics – have worked to determine a timescale for the predicted collapse. They found that the process likely began around the 1920s and has continued since.

"If we continue as business as usual then the tipping will happen within this century," Susanne Ditlevsen says.

In 2022, researchers from the University of New South Wales found that if the AMOC collapsed, we would potentially see more La Niña-like conditions like flooding and higher rainfall across the east coast of Australia, and increased bushfire seasons over the southwestern US, not unlike the conditions these regions experienced during La Niñas in recent years.

NATURE

Australian Mammal of the Year top 10

It's been another exciting vote this year, with more than 1600 nominations submitted and thousands of votes across our ecosystem categories and the knockout round of finals. Things we've learnt this year:

We're fickle

Last year's winner, the southern bent-wing bat failed to make it into the top 10 along with a few other finalists, including our beloved bandicoots.

We're batty about bats

The bent-wing might not have flown through, but the other species swooped to the top of their categories, including Australia's only carnivorous member, the ghost bat.

Familiarity does not guarantee popularity

The platypus aside, many of our better known fauna including wombats, echidnas, and kangaroo and wallaby species tend to take a back seat to our lesser-known mammals. (At *Cosmos*, we love them all ...)

This year's list of the final 10:

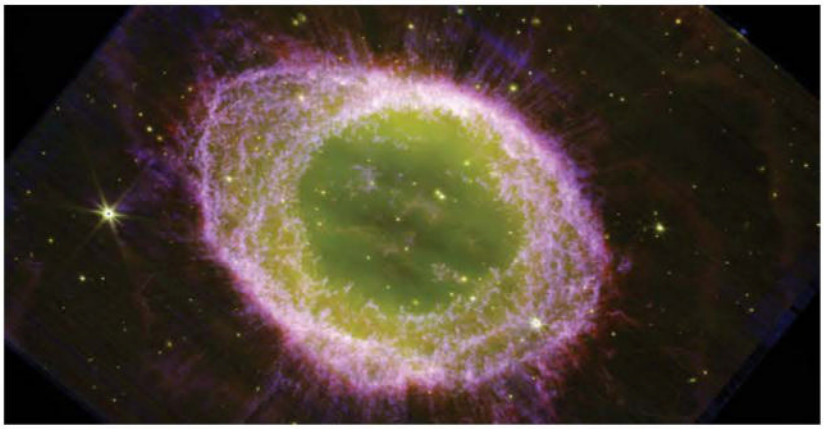
Australian fur seal
Gilbert's potoroo
Spectacled flying fox
Mountain pygmy possum
Golden-tipped bat
Dingo
Platypus
Dugong
Ghost bat
Bilby

To find out who won and read more about our amazing species, visit: cosmosmagazine.com/nature/amoty/

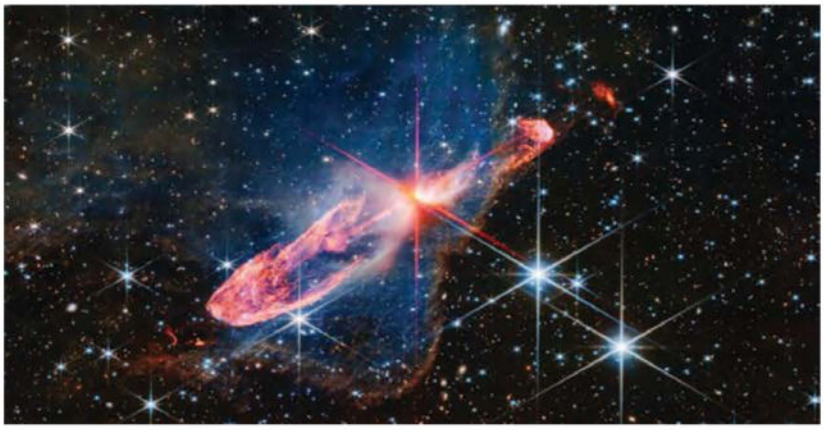
SPACE

James Webb watch

July 12: To celebrate JWST's first anniversary it released this image of the turbulent Rho Ophiuchi cloud complex, the closest star-forming region to Earth.



August 3: Star death in high-definition, showing intricate details of the Ring Nebula's expanding shell and the inner region around the central white dwarf.



July 26: Star birth , showing a tightly bound pair of actively forming stars, known as Herbig-Haro 46/47, in high-resolution near-infrared light.

NASA, ESA, CSA, FEIGE WANG (UNIVERSITY OF ARIZONA), AND JOSEPH DEPASQUALE (STSCI)

PHYSICS

Frustrating new states of matter

A new phase of quantum matter, called a chiral bose-liquid state, has been discovered by experimental physicists.

New phases of matter can be found under extreme conditions like temperatures approaching absolute zero (-273.15°C), or when objects are much smaller than an individual atom, or in very low energy states.

"You find quantum states of matter way out on these fringes," says University of Massachusetts researcher Tigran Sedrakyan, who was part of the team. "And they are much wilder than the three classical states we encounter in our everyday lives."

Sedrakyan and colleagues found the new phase of matter while investigating quantum matter that interacts so strongly it undergoes "kinetic frustration" – particles acting erratically and unpredictably, with infinite possible outcomes. Particles bumping into each other could levitate, or zip off at an angle that doesn't seem physically possible.

Sedrakyan's team has engineered a frustration machine to study these effects. The research is published in *Nature*.

TECHNOLOGY

First step achieved in quantum computer plan

Microsoft provides evidence of an elusive quasiparticle.

MICROSOFT QUANTUM researchers say they have achieved the first milestone in their efforts to create a reliable quantum computer, which the company regards as key to their future.

Director of Sydney Nano Institute and theoretical quantum physicist Stephen Bartlett describes the achievement as significant, but says there's a long way to go before the technology can be used to build a quantum computer.

Around a decade ago Microsoft set out to try to build devices for a quantum computer out of Majorana particles. While these particles had never been observed in nature, theorists predicted they could be created in a particular type of semiconductor device and used to build the components for a robust quantum computer.

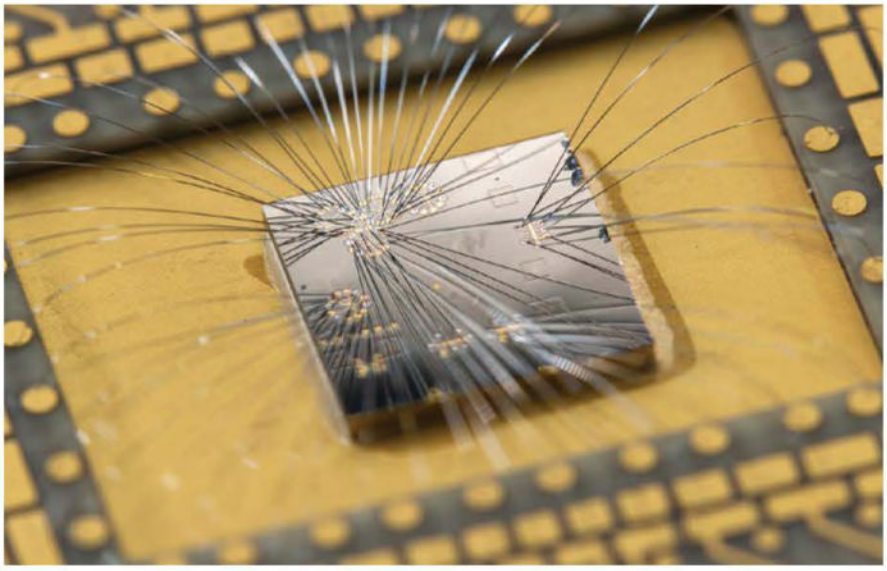
There has been some controversy about Microsoft's initial claims about Majorana particles, but Bartlett says their new paper, published in *Physical Review B*, "is one of the first that's given really strong evidence that they have actually created or observed this new type of particle in this in this system.

"That doesn't mean that now everyone is convinced. But now there's quite a detailed research result published in a reputable scientific journal, and the broad consensus is, okay, they do see strong evidence of this type of particle."

While this represents a key step in Microsoft's plan, there's still many steps before they can make a quantum device out of those observed particles.

Bartlett notes it's still early days, and the technology for building quantum computing devices remains "really open".

Microsoft's Azure quantum chip.



JOHN BRECHER / MICROSOFT

ARCHAEOLOGY

Neolithic French community had "striking" health and nutrition

Two family trees reveal a late Stone Age way of life.

ANCIENT DNA from 94 individuals buried at the Neolithic site at Gurgy 'Les Noisats' in northern France has provided a picture of a community that existed 6,700 years ago.

Two family trees have been constructed from the data. One connects 64 individuals over seven generations, making it the largest lineage reconstructed from ancient DNA to date. The second links 12 individuals over five generations.

Researchers used a range of techniques to analyse the ancient DNA. They combined genome-wide analysis with strontium isotope ratio values, mitochondrial DNA (maternal lineages) and Y-chromosome (paternal lineages) data, age-at-death, and genetic sex to build a picture of the ancient community.

The data reveals a strong lineage along the paternal line. Mitochondrial DNA (from the mother) shows evidence that most females in the community came from outside Gurgy before having children, while the males remained where they were born. One male individual was found from whom everyone in the larger family tree was descended.

Females from outside Gurgy were only distantly related, suggesting they came from a network of nearby communities instead of just one group.

"We observe a large number of full siblings who have reached reproductive age," says first author Maïté Rivollat. "Combined with the expected equal number of females and significant number of deceased infants, this indicates large family sizes, a high fertility rate and generally stable conditions of health and nutrition, which is quite striking for such ancient times."

Gurgy was only settled for about 100 years before the Neolithic peoples left.

The results are published in *Nature*.

SPACE

This galaxy is missing dark matter

A massive galaxy has been found to contain almost no dark matter.

NGC 1277 is several times the mass of the Milky Way. Present cosmological models predict that a galaxy of this size should be 10–70% dark matter. But according to a new study published in *Astronomy and Astrophysics*, NGC 1277 contains no more than 5% dark matter.

"This discrepancy between the observations and what we would expect is a puzzle, and maybe even a challenge for the standard model," says researcher Ignacio Trujillo, from Spain's University of La Laguna (ULL) and the International Astronomical Center (IAC).

The team suggests two possibilities.

"One is that the gravitational interaction with the surrounding medium within the galaxy cluster in which this galaxy is situated has stripped out the dark matter," says Anna Ferré-Mateu, also from IAC and ULL. "The other is that the dark matter was driven out of the system when the galaxy formed by the merging of protogalactic fragments, which gave rise to the relic galaxy."

EDUARDO FONSECA ARRAES / MOMENT / GETTY.

ANTHROPOLOGY

Robot preachers receive lower donations, study shows

Do congregations trust robotic religious leaders?

Robot preachers and AI sermons are seen as less credible and are less likely to garner donations than people, according to a new study published in the *Journal of Experimental Psychology: General*.

"I wouldn't be so sure that religious leaders will ever be fully automated because religious leaders need credibility, and robots aren't credible," says lead author Joshua Conrad Jackson, from the University of Chicago, US.

Jackson and colleagues conducted three experiments – at a Buddhist temple, at a Taoist temple, and in an online survey of Christians.

In the first experiment, the team surveyed over 400 people as they left the Kodai-ji Zen Temple in Kyoto, Japan. In 2019, this 400-year-old temple introduced a robot called Mindar to preach 25-minute sermons.

"Some people visit Kodai-ji Temple specifically to see Mindar, but since the temple is already well-established, many people come to the temple with no intent of visiting Mindar," the researchers write.

They excluded those from the study who visited to see Mindar, leaving 398 people who had either seen a robot or human sermon, but not both. Participants consistently rated the robot preacher as slightly less credible.

The researchers also gave participants ¥1000 (A$10.50) for completing the survey, of which they could donate any amount to the temple. Participants who'd seen the human were more likely to donate more back to the temple.

The second experiment focused on a Taoist temple in Singapore, where either a human preacher or a humanoid robot delivered an identical sermon to visitors on different days. The researchers surveyed 239 visitors and provided them with S$5 (A$5.60). Again, participants who'd seen the robot consistently thought it slightly less credible, and donated less of their money back.

The third experiment surveyed 274 Christians from the US online. Participants read a sermon written by Jackson, but were told that it had been written either by a human preacher or an AI. When asked to rate its credibility, those who'd been told it was written by an AI rated it as less credible.

"Robots and AI programs can't truly hold any religious beliefs so religious organisations may see declining commitment from their congregations if they rely more on technology than on human leaders who can demonstrate their faith," says Jackson.

Kannon Mindar, the android installed in Kodai-ji Zen Temple in Kyoto, Japan.

URPHOTO / GETTY IMAGE

PALAEONTOLOGY

Flightless pterosaur ancestor found in Brazil

FOSSILISED REMAINS found in Brazil of a creature that lived 230 million years ago are believed to be a precursor to pterosaurs.

Venetoraptor gassenae, described in a paper published in *Nature*, was a small, land-dwelling, bipedal reptile about a metre in length and weighing 4–8 kg. It also had a toothless beak like modern birds of prey. Its large hands had scimitar-like claws.

It belonged to a clade of reptile known as lagerpetids. These ancient reptiles lived during the Triassic period and are considered the closest relatives of pterosaurs.

Pterosaurs emerged in the late Triassic and were the first vertebrates to use powered flight. A 200-million-year-old desert-dwelling animal first described earlier this year is among the oldest known pterosaurs.

Pterosaurs went on to dominate the skies but met the same fate as the non-avian dinosaurs, which went extinct 66 million years ago.

Focus: Football

1 **A football-shaped molecule may hold the key to our clean energy future. Carbon nanotubes created by buckminsterfullerenes are light, efficient and highly conductive**

2 A new genus of spiders has been named *Socca*, with species names such as *johnnywarreni* and *arena* also celebrating the game.

3 **Innovations to the football for the Women's World Cup this year include motion sensors that measure acceleration and direction to assist referees.**

4 Concussion might not be sports players' greatest concern as research into chronic traumatic encephalopathy shows small repeated impacts – such as when players practise headers – could cause greater damage.

5 AI mannequins trained to play football through videos of human movement and reward-based reinforcement for ball kicking and teamwork – but no sport rules – played a competent match.

6 **Bending a soccer ball into goal is not just sporting prowess: there's some exciting fluid mechanics and physics involved as well.**

www.cosmosmagazine.com/ 01 science/chemistry/buckyballs-soccer-football-molecules/ 02 science/biology/soccer-spiders-take-the-field/ 03 health/body-and-mind/2023-fifa-womens-world-cup-ball/ 04 health/football-header-brain-injury-concussion/ 05 technology/machine-learning-soccer/ 06 health/body-and-mind/bend-mccabe-world-cup-curve-ball/

LIU ET AL., SCI. ROBOT. 7, EABO0235.

PALAEONTOLOGY

Armoured archosaur opens new chapter on dinosaur evolution

Palaeontologists from the American Museum of Natural History have described a new species of archosaur, the dinosaur-like reptile which predated dinosaurs.

In a paper in the *Zoological Journal of the Linnean Society*, researchers describe the species *Mambachiton fiandohana* from a 235 million-year-old fossil found in Madagascar.

Archosaurs evolved into two main branches: the bird line (including pterosaurs and dinosaurs) and the crocodilian line (including crocodiles, alligators, caimans and gharials).

The newly described Mambachiton is the earliest known member of the bird line of archosaur evolution. It also has armour, a common feature in crocodilians but a rare feature in bird-line archosaurs.

The find shows that armour was an ancestral characteristic of bird-line archosaurs that was lost in evolution for a time, later reappearing in dinosaurs, likely as a result of changing interactions with the ecosystem.

The species was around 1.5 to 2 metres long, weighing 10 to 20 kilograms.

NESBITT ET AL. USAF MUSEUM. PA IMAGES / GETTY IMAGES.

Guess the object

High flyers

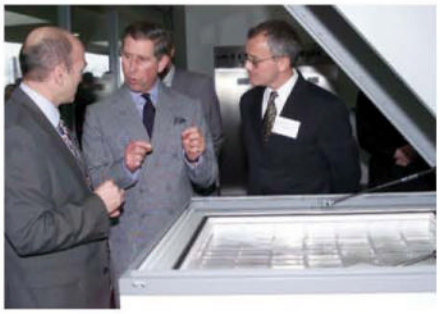
Okay, so let's be clear it's a cockpit: the cockpit of what, is the question. It's one of the more famous aircraft from the period the average aviation tragic would regard as the golden age of speed. As the photo suggests, it's not a particularly big craft, and it was flown by a solo pilot.

There's something especially nifty about the aircraft's controls – bonus points for anyone that can tell us about them. And more bonus points if you can name at least one... naaaah, let's make it two, of the pilots that flew it.

We know you can Google it, but where's the fun in that? Tell us what you think it is. The correct answer – and/or the most creative – will be published in our next issue. Send your hunches to contribute@cosmosmagazine.com

King of...what?

A range of amusing guesses greeted last issue's object. "An excellent example of a quite advanced early camping stove," opined Sue Fletcher McAinsh. Phil thought it "a high-resolution photocopier from the '70s, used in offices where bored staff photocopy their buttocks". Hmm. While he didn't know its name, Aiden Blanchfield believed it to be used "to detect photons that have split while travelling through the ozone layer". In fact, it's a two-way thermogradient plate, which investigates seed germination and temperature combinations. Hizzoner Prince Charles was shown the device before opening the Millennium Seed Bank, at the Royal Botanic Gardens, Kew, London, in 2000.



MEDICINE

For better vaccines, scientists mess with DNA to form origami

Next-gen cargo delivery – on the nanoscale.

PICTURE A virus. Are you thinking of the spiky ball shape of COVID or HIV? Or the alien-like spines of a bacteriophage?

While virus shapes are incredibly versatile, an international team of researchers decided to get even more creative, using DNA origami templates to mould how viruses assemble themselves. The fun-shaped results will hopefully allow scientists to create better vaccines.

Viruses are simply genetic information-carrying boxes. The box is called the capsid, and this protects all the important DNA or RNA inside.

Capsids are normally made up of 20 triangular faces (like a 20-sided die), but they can also have fewer

sides, or be helical and look more like tubes.

To form these capsids, the DNA or RNA inside the capsid has specific instructions for the machinery inside a living cell on how to make more. When a virus infects a cell, the instructions are pulled out and the cell starts producing new parts.

The researchers took this already fine-tuned process and added an extra bit – origami.

DNA origami is the technique of folding DNA into shapes. The team – some of whom are from Griffith University in Queensland – created 3D hoops and tubes of different sizes all made of DNA, which the capsid then grew over.

"This activity is more like wrapping a present – the virus proteins deposit on top of the different shape that is defined by the DNA origami shape," says Frank Sainsbury, a virologist at Griffith.

"And different virus proteins are like different wrapping paper, which would be relevant to different uses of the coated DNA origami."

Although this does sound a bit like a viral arts and crafts project, the reason for it is important. The researchers found that the capsid still worked at protecting the inner DNA, meaning that these could be used for genetic vaccines, or delivery systems of certain genetic information.

Basically, the design allowed the team to use the virus's ability to sneak into our body for their own ends.

The research has been published in *Nature Nanotechnology*.

TECHNOLOGY

$600k to put brain cells on computer chips

Hundreds of thousands of brain cells will soon be grown in a dish and trained to undertake tasks.

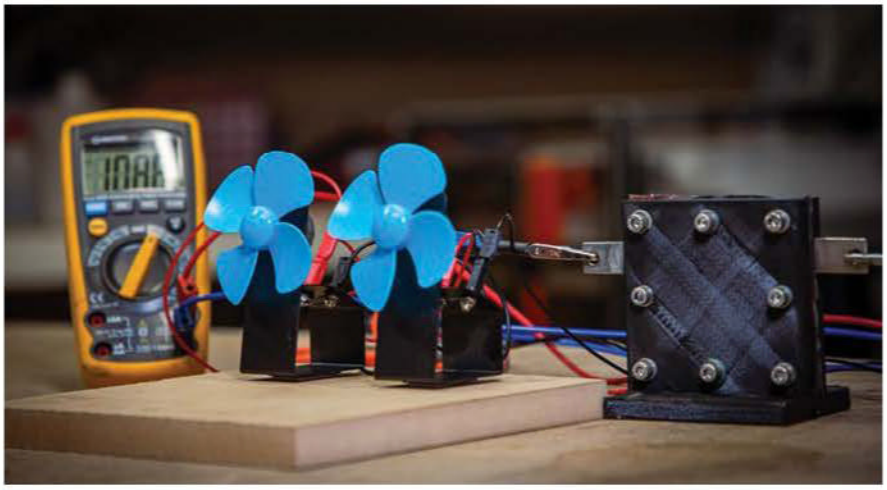
The Turner Institute for Brain and Mental Health, at Monash University, was granted $600,000 by Australia's National Intelligence and Security Discovery Research Grants Program to undertake the research.

It will work with Cortical Labs, which in 2022 developed the 'Dishbrain' – an aggregation of 800,000 mouse neurons, with the neural capacity of a bee – and taught it to play the retro game Pong. The collaboration aims to extend this work to develop AI that can emulate biological neural networks and "learn".

"This new technology capability in future may eventually surpass the performance of existing, purely silicon-based hardware," says project lead Adeel Razi from the Turner Institute.

"The outcomes of such research would have significant implications across multiple fields such as, but not limited to, planning, robotics, advanced automation, brain-machine interfaces, and drug discovery, giving Australia a significant strategic advantage."

OSAKAWAYNE STUDIOS / GETTY IMAGES.



DISCOVERY

Proton battery: hydrogen without the gas

Powering tiny fans today, your house tomorrow.

HYDROGEN: AN energy-dense abundant resource, but also a gas that's difficult to store and transport. Batteries: excellent at storing energy, but containing precious metals like lithium and cobalt.

Now researchers at RMIT University in Melbourne have combined the best of both worlds, with an experimental battery that uses hydrogen.

Their fast-charging "proton battery" is made with completely renewable resources, and operates mostly on water and activated carbon. While only powerful enough to run a handheld fan for a few minutes, by weight these tiny batteries are already comparable with lithium-ion.

"The proton battery has evolved from our attempts to get a simpler, more efficient, hydrogen-based energy storage system," says research lead John Andrews from RMIT.

Traditional green hydrogen fuel systems take water (H_2O), and use electricity to split it into hydrogen gas (H_2) and oxygen gas (O_2). But this reaction has a few more steps hidden within it: the hydrogen atoms are first converted into positively charged hydrogen ions (H^+), before they pair up and become H_2 gas.

The proton battery, in its current form, is powerful enough to run some fans for a few minutes – but it could get much bigger. It was developed by RMIT researchers (from left) Dr Seyed Niya, Dr Shahin Heidari and Professor John Andrews.

Then, hydrogen is burned or reacted with oxygen again, releasing energy and water once more.

"The basic reaction that we're using is similar to what is used in a hydrogen fuel cell-based energy storage system," explains Andrews. "So we start with water, we split that in a cell that's very like an electrolyser that's used in a hydrogen system, and then you get protons, H^+."

Hydrogen atoms mostly just have one positively charged proton and one negatively charged electron. Remove the electron, and you have an H^+ ion – a proton.

"Protons are then passed through a membrane, same as in a fuel cell, but they then enter a porous carbon electrode that is negatively charged. The protons are then stored within this carbon matrix," says Andrews.

"In your normal hydrogen system, those protons combine in pairs with electrons to give you hydrogen gas, and then you have to store the hydrogen gas.

"But in the proton battery, there's no gas. We're storing protons directly in the carbon electrode, which is part of the cell."

Then, when it's time to discharge the battery, those protons react with oxygen in the air, releasing energy and generating water again.

"We've cut out that step of producing and having to store hydrogen gas. The protons are stored directly, which is safer, and it is much more energy efficient," says Andrews.

The electrode that stores these protons best is a type of material called activated carbon.

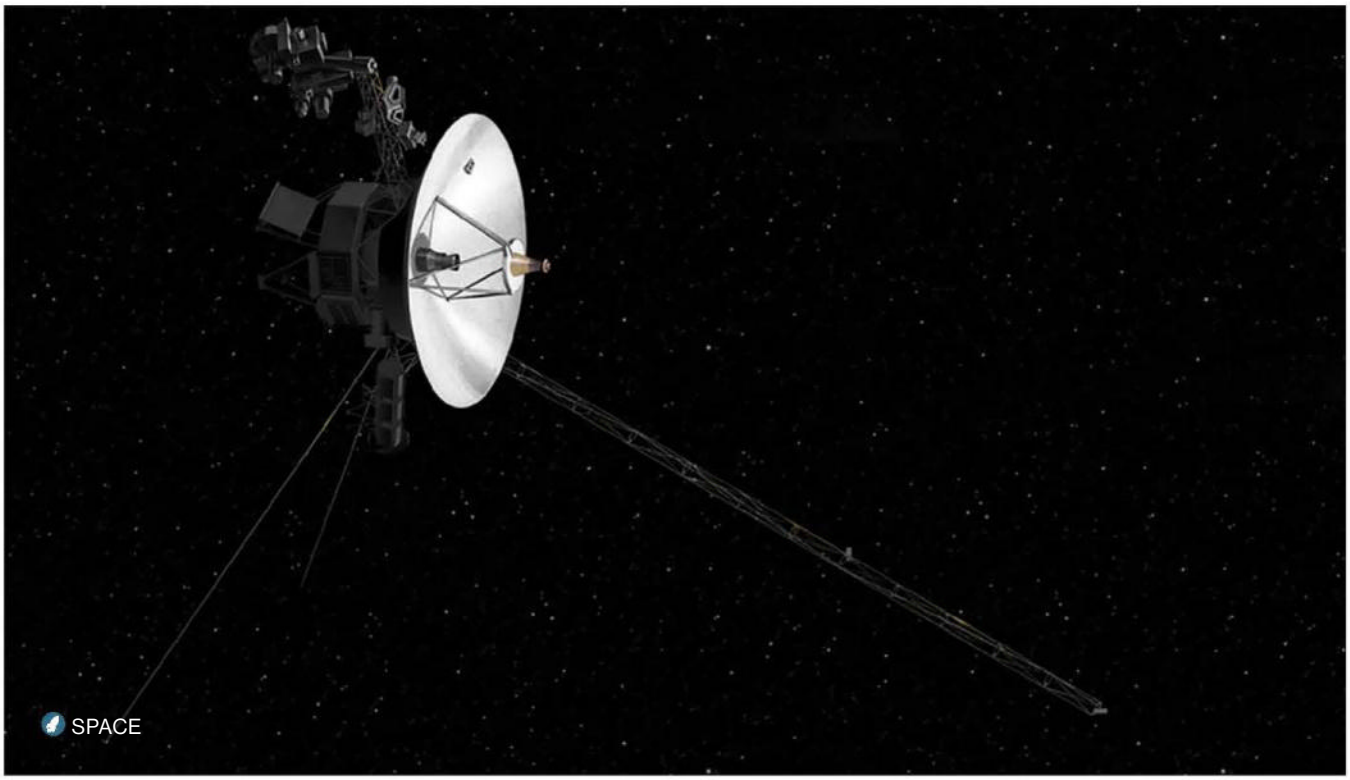
"Activated carbon is a carbon that's been hollowed out, and it's got a very high internal surface area," he explains. "It's got lots of pores and channels connecting the pores."

The carbon can be made from a number of feedstocks, such as wood, wheat straw or coal.

"We're quite optimistic about the eventual economics of the device," Andrews says. "The primary sources are very abundant and very cheap."

A partnership with an Italian company hopes to see a prototype big enough for home storage within a couple of years.

RMIT UNIVERSITY.



How did NASA lose and recover Voyager 2?

Tiny craft travelling for decades can still phone home.

FOR SUZANNE DODD, Project Manager of NASA's Voyager Interstellar Mission, the Voyager 1 and Voyager 2 spacecraft are "sort of my first love – and true love".

Her love for these vintage interstellar explorers, launched two weeks apart in 1977, has bloomed over many years. She began working on the Voyager mission in 1984, shortly after graduating from college, before leaving to work on other NASA projects, such as the Cassini-Huygens space research mission. Then, in 2010 she returned to where her career had started to take on her current role.

By then, the twin craft had long completed their primary mission of conducting closeup studies of Jupiter and Saturn. Each is equipped with a range of instruments, including television cameras, infrared and ultraviolet sensors and cosmic-ray and charged-particle sensors, as well as a gold-plated record containing sounds and images selected to portray life and culture on Earth to anyone or anything who might find them.

On 25 August 2012, Voyager 1 left our solar system and entered interstellar space. Six years later, Voyager 2 achieved the same milestone.

In the years since, the two spacecraft have continued transmitting the information they collect about things such as the interstellar magnetic field and cosmic rays, back to Earth via the Deep Space Network (DSN) – NASA's trio of giant radio antennas located equidistantly around the world, which support interplanetary spacecraft missions.

But on 21 July, NASA suddenly lost contact with Voyager 2. To make a fine adjustment to Voyager 2's antennae so that it pointed more closely to Earth, flight controllers had built a precise command to send to the spacecraft. But they'd realised that the command had the wrong parameters in it.

"We rebuilt the command with the correct parameters," Dodd explains. "But what happened is that we accidentally sent the earlier version of the command – not the updated one."

This caused Voyager 2's antennae to point 2° away from Earth, severing communication with flight controllers. Although Dodd was confident that contact with Voyager 2 would have been restored in mid-October when the spacecraft was due to automatically realign itself with Earth using the Sun and Canopus, she didn't want to rely on this protection feature.

But how to manually restore contact with a spacecraft the size of an old Volkswagen beetle that was more than 19 billion kilometres from Earth and hurtling through deep space at a speed of over 56,000 km/h?

Critical to this very ambitious goal was the Canberra Deep Space

NASA

Communication Complex (CDSCC), one of the three facilities that form the DSN.

As Glen Nagle from the CDSCC explains: "After Voyager 2's encounter with Neptune in 1989, it headed southward out of the planetary ecliptic. And it's now so far south that our sister stations in the Northern Hemisphere can't see it because Earth is in the way.

"So, since 2002, it's kind of been exclusively ours," Nagle laughs.

The first part of the plan involved using Deep Space Station 43 to listen for its carrier signal – "the heartbeat of the spacecraft", according to Nagle. Promisingly, scientists at CDSCC detected a faint signal that resembled Voyager 2's. They listened to the sounds of deep space a second time and detected the same whisper.

After processing the data "to eliminate the junk mail of the universe" – as Nagle puts it – the scientists in Australia sent it to Dodd and her team in the United States for analysis, which confirmed that the signal was from Voyager 2.

Following this, the CDSCC transmitted what Nagle calls an "interstellar cooee". This transmission was approximately 250% stronger than normal ones to increase the chances of the spacecraft's antennae detecting it.

> They will ultimately outlast the Earth and the Sun

Voyager 2 flew by Jupiter's moon Europa (top) in 1979. Suzanne Dodd (above) is NASA's mission project manager.

"And that transmission contained a single command," Nagle says. "'which was: 'reorientate your antennae back to Earth.'"

A long wait ensued: it would take 18.5 hours for the transmission to reach Voyager 2 – and another 18.5 hours for scientists to know if it did. They weren't confident. But after 37 nervous hours, a signal arrived. There was no doubt where it had come from: contact with the spacecraft was restored.

"There were cheers and high-fives in the control room," Nagle says.

Dodd says her team at NASA is conducting a thorough investigation into the incident to help ensure that something like it doesn't happen again. But she knows that eventually the plutonium power source of the spacecraft she loves will eventually run dry – and contact with the two Voyagers will be lost forever.

"If you want to think really long term," Nagle says, "they will ultimately outlast the Earth and the Sun and be the last reminder that we ever existed in the universe." And maybe – just maybe – they will prove to an alien civilisation that there is – or at least once was – other life out there.

HERITAGE IMAGES / GETTY IMAGES. NASA / CARLA CIOFFI.

Fanning the flame

Mathematician **Valentina Wheeler** is working on how to describe flame – so we can model how fire fronts merge, or why bubbles pop.

A grim drone image (above) shows a fire front ripping through the bush in northern Australia, during the devastating fire season of 2019/2020.

Every mathematician gets excited by a new breakthrough – it's like a mountain climber finding a new route to climb in the Himalayas. Sometimes these breakthroughs have applications to things we know, but most of the time the applications are not apparent. We just enjoy answering mathematical questions.

It's like solving a puzzle. It all starts with the desire to answer questions using analytical thinking and our problem-solving minds. This is why graduates in mathematics are sought after in a lot of industries that aren't necessarily maths-based: they're willing to inquire and analyse to find solutions.

Some people can work things out in their head – they're the geniuses. But I need paper and pen, and I make a mess! The floor of my workspace is covered with papers. You're always going to stumble and make mistakes – sometimes massive ones. We're definitely not perfect. I often put mistakes in my lectures to see which students fish them out. It's part of the process – it's a fun thing.

ROBERT IRWIN / COURTESY NATURAL HISTORY MUSEUM, 2021 WILDLIFE PHOTOGRAPHER OF THE YEAR PEOPLES CHOICE

Everyone assumes that I'm really good with numbers. I'm not! I do shapes. I'm a very visual person. My specialty is geometric analysis. I take a geometric object and try to describe its properties with a partial differential equation.

When I look at anything that happens in everyday life, I'm always thinking, "How can that movement or shape be described?" You see a fire and how it burns a piece of paper – I'm like, "How can I describe that?" My brain just works this way. How is the wind moving those branches? How do the waves arrive on the shore? Maths is hidden in every single thing in nature. If somebody can describe this movement or change, then you can study it.

I've been focused lately on geometric objects that move based on energy. That's what nature does: it tries to minimise or maximise some sort of energy. So we take that energy and do something called calculus of variations – then we can obtain a Euler-Lagrange equation too. This way we get our equations that we can study.

Some of my work is now used to model how fire fronts merge. I'm not an expert in bushfires at all, but I know Australia has been plagued by them. I was talking to Jason Sharples from UNSW Canberra, who is professor of bushfire dynamics; he's an expert in modelling, with a background in pure mathematics and curvature flow. We were discussing how we can model moving fronts. When you simplify a bushfire, it's basically just a line that you put in a plane. This "real" fire line has similarities in its movement to the curvature flows that we're studying. We have some interesting ideas there that we're working on.

> "Maths is hidden in every single thing in nature. If somebody can describe this movement or change, then you can study it.

I'm also focusing at the moment on trying to answer questions of minimal surfaces and constantly curvatured surfaces with boundaries. Think about foams and bubbles – take two or three bubbles and cluster them together. How would they stay in equilibrium form? After a while the bubbles start popping. We're thinking about where that configuration can become stable. And we're trying to solve that using curvature flow. Then comes the question, what sort of minimal surface can you have? We're now looking at double bubble conjectures and things like this.

I've also recently been working together with a couple of collaborators on clusters and space partition problems. We're trying to think how we can partition the space in x numbers of regions that each contain a certain volume and then have a certain area, and we're trying to do this using a curvature flow.

These clusters or partition problems have applications when describing foams or other materials. You can use them, for example, when you want to construct new materials which are lightweight but have high strength, or to improve thermal or acoustic insulation.

If we're able to create a complete theory about it, maybe then we can put it into practice by constructing foams which might be used in the oil or gas industry to recover oil spills or extinguish fires. Or it might be used in the food industry to stabilise things that you want to put on the shelf, like whipped cream. Or there might be direct application in biology, for example, if somebody is trying to construct some sort of bone material – that might also involve a cluster of cells.

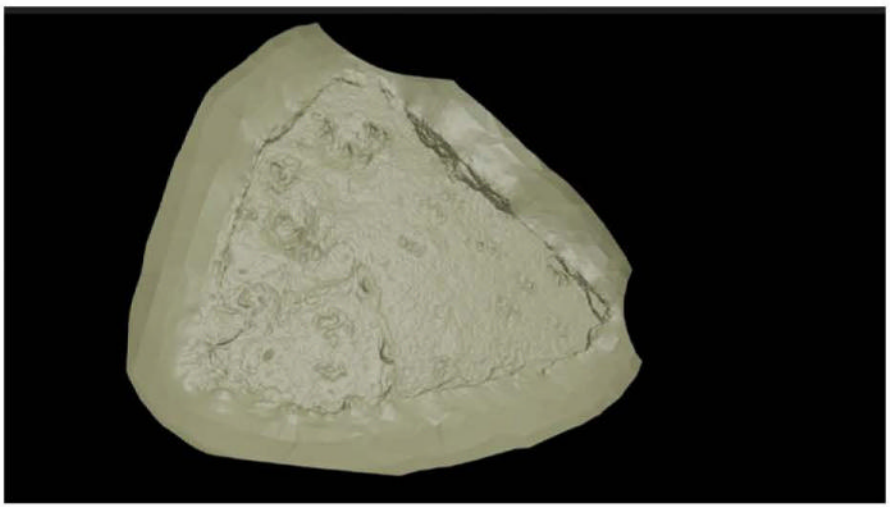
The applications could eventually be found in many fields or industries, but that's not our work. We're just the mathematicians who think: how can I do this? And then: what's the next big problem?

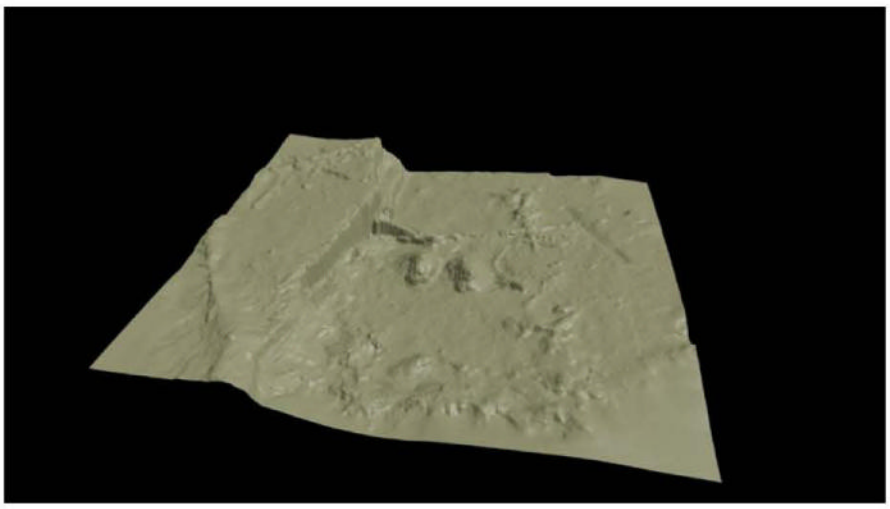
UNIVERSITY OF WOLLONGONG

DR VALENTINA WHEELER is a Senior Research Fellow in the School of Mathematics and Applied Statistics at the University of Wollongong, and the winner of the 2023 Christopher Heyde Medal.

Fossil forensics

Palaeontologist **Aaron Camens** is using virtual technologies to help fill in the missing links in Australia's fossil record.





I am one of those tragics who decided when I was five that I was going to be a palaeontologist. But when I went through my undergrad, the university didn't offer a specific palaeontology degree. Instead, I majored in zoology and geology – because when you put rocks and animals together, you get palaeontology.

The Australian fossil record is pretty patchy. The bulk of the evidence shows that there was a big megafaunal cohort until about 45,000 years ago. But by 40,000 years ago they were just about all gone – the only megafauna left were kangaroos, emus and crocodiles. Some megafaunal taxa have only a couple of representations in the fossil record, so we don't know much at all about when they went extinct.

The Holy Grail isn't so much finding a specific animal, but finding fossils from a specific time period. At the moment, we've got a reasonable record of the modern Australian groups of animals from about 25 million years ago (mya) onwards. But the molecular evidence suggests that many of those families originated 35 mya. We don't have any fossils representing what's going on in that missing time period.

A big part of the challenge is that our Australian fauna have evolved in complete isolation for at least 50 million years. If we found a site from that particular time period, 35–40 mya, it would clarify so much of our understanding of the early evolution of the modern groups of Australian animals. Unfortunately, there are very few sediments of the right age preserved in Australia.

Some of the places we go to are very arid environments. I've just been out around Cooper Creek, which is one of two main rivers that flow into the eastern side of Lake Eyre in South Australia. The current drainage pattern is eroding through the sediments from what we call palaeochannels, so we are seeing good potential for fossils to be exposed.

After spending time in places like Lake Eyre and Lake Frome, you come to love desert environments and develop an appreciation for how these ecosystems function today. It's also our job to imagine what these landscapes looked like millions of years ago. The evidence shows that a lot of Australia was much more heavily forested than it is today– go back 25-20 mya and parts of Central Australia were

VIRTUAL AUSTRALIAN MUSEUM OF PALAEONTOLOGY

Dr Aaron Camens loves to have one foot in the past – or multiple. He uses scanning technologies to study traces of the megafauna that once roamed Australia's arid interior, including the footprints of hopping kangaroos from Western Australia (opposite page) and fossils of the extinct *Sthenurus stirlingi*, one of the largest kangaroos ever (below).

rainforest. In Lake Callabonna, northeast of the Flinders Ranges, we're finding thousands of megafauna animals that got stuck in mud. They show us that the vegetation was once very different, just to be able to support them.

Lake-level sequences from about 45,000-50,000 years ago show that Lake Eyre and Lake Frome went through a catastrophic drying phase. Prior to that they were almost permanently full of fresh water, transforming the landscape by supporting much more vegetation, with flow-on effects for the rest of the ecosystem.

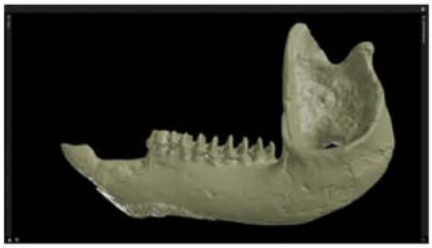
But it's the fossils there that excite us. New technologies now allow us amazing insights – from various kinds of x-rays and CT scans to the really high-powered tech like synchrotrons and neutron beams. These can look inside of bones or inside the concretions that contain fossils, giving us the ability to image and investigate fossils in a completely non-invasive way.

It's very rare that soft tissue is preserved, for example, and in the process of cleaning and preparing bones, any existing soft tissue impression could easily be destroyed. But the new imaging technology gives us a permanent three-dimensional record of soft-tissue impression.

I also work a lot with fossil footprints. Quite often they're in remote areas, or in places where it isn't easy to take out supplies to make casts. Instead, a technology called photogrammetry allows us to use computer software to turn a series of photos into a three-dimensional image.

Recently, we found some trackways from a bipedally striding kangaroo – walking, rather than hopping. Figuring out what made the tracks requires a whole sequence of forensic investigations. We look at the sediments and their age, the environment, what the fossil record tells us about the fauna at the time, and what we know about the shapes of the different feet of the animals that were there. Through a process of elimination, we can figure out what species made the tracks, or at least come up with possible candidates.

> The Holy Grail isn't so much finding a specific animal, but fossils from a specific time period.



In this case, we were able to eliminate everything except the kangaroos. In the past, a couple of studies based on observations of skeletal morphology suggested that some extinct kangaroos were bipedally striding. But our trackways are the first direct evidence that some moved in that way.

These trackways are about 3.5 million years old, but it's been proposed that the group that they belong to, the big short-faced sthenurine kangaroos, all walked bipedally until they died out about 40,000 years ago.

There are two competing hypotheses about why they disappeared – driven extinct by climate change, or hunted by the first people to arrive here. While we've got evidence at a number of sites showing that megafauna were able to withstand some variation in climate, we don't have any direct evidence of humans hunting megafauna in Australia.

So there's a lack of evidence either way. Which means we have plenty of work to do!

DR AARON CAMENS is Lecturer in Palaeontology at Flinders University and a leader of the team in the Flinders Palaeontology Lab.

FLINDERS UNIVERSITY

Archaeology by ancestor

Led for the first time by Indigenous archaeologists, a dig team at a key site in Vanuatu is tapping into the Pacific's ancient past. **Prianka Srinivasan** was there to witness something special.

I'm standing at an archaeological dig at Pang Pang, Vanuatu. About a dozen people are hard at work under the dappled light of the forest, sifting through soil, scrubbing at bits of shells and bone, and painstakingly digging in square pavilions, neatly marked with bright yellow string. One of the locals has hooked up his phone to a speaker, and now a steady pulse of reggae and pan-pipes accompanies the sound of scraping dirt and chatter among the team. The site could be easily lost in the dense green foliage – only a large banyan tree marks the entrance from the main road. To get there, my guide and I had to clamber under its roots and then follow a winding trail that cut past the riverbank. The canopy then opens to small flat hills, about a metre or so tall, upon which all the activity is taking place.

One of the workers pulls four recently-found pottery shards, each about the size of a postage stamp, out of a ziplock bag and lays them flat on his palm for me to see. To an untrained eye, they don't look like much. Under a crust of dirt, the deep orange clay peeks out. Each piece is marked with tell-tale puncture patterns. Definitely Lapita.

"This is from a time before Jesus," the man says. A woman from a nearby village, there to see the excavation, raises her eyebrows in awe.

The Lapita pottery shards have been an impressive find for the team, which began searching the area last year. Their discovery marks this region, on the east coast of Vanuatu's main Efate Island, as one of the first human settlements of the Pacific, dated around 3,000 years before present (BP).

Discovering Lapita's legacy

The Lapita people are considered the Pacific's ancestors, believed to have set sail from Papua across the Pacific Ocean to populate its many islands. Tracing their journey through the sea has been notoriously hard for researchers. Only a few

ALL IMAGES: PRIANKA SRINIVASAN

When the Lapita people set sail from the Bismarck Archipelago for the vast blue horizon of the Pacific Ocean, they were beginning the most incredible journey the world has ever seen. Now, indigenous archaeologists in Vanuatu are mapping out their ancestors' histories.

SEIJI SEIJI / UNSPLASH

Lapita remains have been recovered, offering archaeologists very little genetic material to map out the colonisation of the region.

But some of the clues helping modern archaeologists fill these gaps are remnants of pottery, like those found in Pang Pang. The Lapita decorated vessels by pressing the edges of shells and other tools into the wet clay, creating distinctive pinprick patterns. By studying the evolution of these designs, researchers can follow the Lapita's journey and track the development of the Pacific's unique cultural groups.

The earliest pottery pieces dating back to 3,500 BP have been found in the Bismarck region of Papua New Guinea, therefore considered the birthplace of Lapita's Pacific lineage. How exactly Lapita's ancestors got here is up for some debate, but genetic evidence shows they descended from Austronesian people, who lived in Taiwan and nearby Southeast Asian islands.

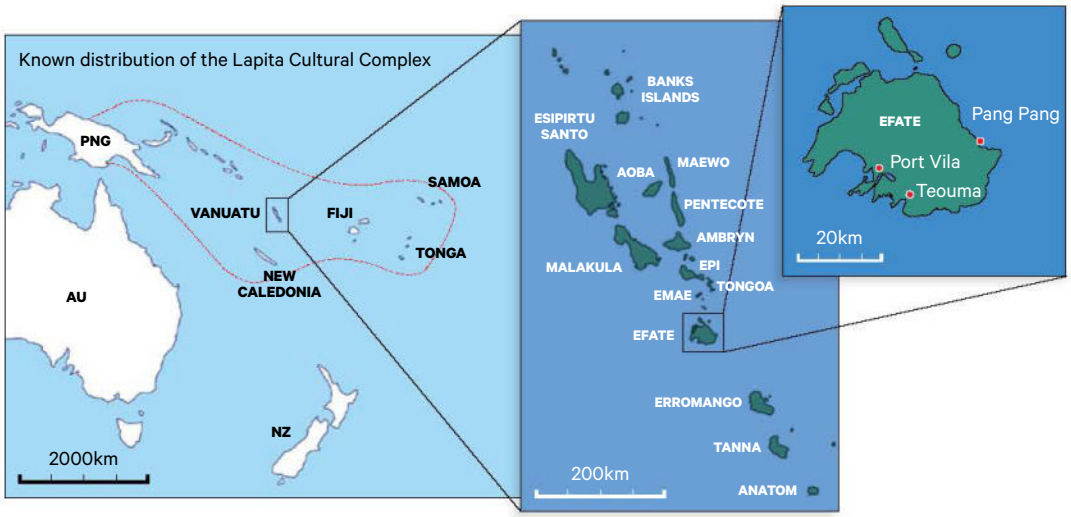
It's likely these early seafarers were met by existing Papuan populations in Bismarck, who had been living there as early as 65,000 BP. Some Lapita would move further into New Guinea, mixing with local Papuans. But others are believed to have rapidly travelled south from the Bismarck islands, before heading through Melanesia and east to Polynesia. Upolu in Samoa is the easternmost island where Lapita pottery has been found.

The speed of the Lapita expansion is incredible – in just 2,500 years, Lapita and their descendants colonised the Pacific, a region comprising one-tenth of the world. Rather than traversing the region in a wave of migration, the current prevailing theory, first proposed by New Zealand archaeologists in 2006, is that the Lapita leapfrogged to different islands in their outrigger canoes, bypassing much of the Solomon Islands archipelago to settle in Vanuatu and its nearby islands. That's why these areas are considered a gateway to Pacific migration – likely a first stop for the Lapita out of Bismarck, and from where further settlement of remote islands took place.

Edson Willie, an archaeologist from Vanuatu's Cultural Centre (Vanuatu Kaljoral Senta, VKS) has been studying the Lapita for most of his career and is one of the lead researchers at Pang Pang. He became Vanuatu's first archaeology graduate, earning his degree at the University of Papua New Guinea.

Tall and imposing, with a furrowed brow that often forms over his carefully selected words, Willie

"To an untrained eye, they don't look like much. Under a crust of dirt, the deep orange clay peeks out. Each piece is marked with puncture patterns. Definitely Lapita."



Working with the community has allowed ni-Vanuatu archaeologist Lucas Sarvanu (opposite page) and team to identify key Lapita sites in Pang Pang. Locals (left) have been recruited to help excavate artefacts such as pots (centre); these were created by partially superimposing layers of clay, then were fired between 600 and 750°C.

talks passionately about Vanuatu's history and culture. When I ask him about being Vanuatu's first ever archaeologist, he corrects me.

"I'm Vanuatu's first archaeologist with a degree," he says in Bislama. "There are plenty of local people who do the work of archaeologists but don't have a degree and aren't Western-educated."

That respect for local knowledge bleeds into Willie's work. At the site in Pang Pang, Willie sits beside the village workers, wrist deep in muddy water, scrubbing shells and laughing with them.

Willie believes researchers have only "scratched the surface" of understanding the Lapita people's journey, their cultural practices and impacts on the islands, despite their importance to the Pacific's history.

"When we find evidence of Lapita, it connects our people of the Pacific – not just Melanesians but Polynesians too," Willie says. "We've uncovered a bit, slowly we're uncovering more about where they went and how they lived."

The village of Pang Pang is like many in Vanuatu. A dozen or so traditional houses, covered in native natangura palm (*Metroxylon warburgii*) leaves lay nestled between tall coconut palms and mango trees. But since the find in October 2022, elements of the community have transformed.

Villagers have become part of the excavation team in the nearby forest, working with a group of international researchers, including Associate Professor Stuart Bedford from the Australian National University and Dr Frédérique Valentin from the French National Centre for Scientific Research (CNRS). Often, dignitaries from Vanuatu's capital Port Vila, 25 kilometres south-east, also visit. The group has been told that the French ambassador, whose embassy has funded some of the excavation, will be paying a visit very soon.

At the site, the local men squat over a shallow dish, scrubbing at newly uncovered shells. Nearby, undergraduate archaeology students from the Australian National University, on a field trip during their winter break, carefully sift through the dirt from a square hole about a metre deep.

"I'm glad that all these people are here, because we didn't really know about our own history," says

(MAP) GREG BARTON. (POT) MUSÉE DU QUAI BRANLY

The pottery unearthed by the Pang Pang community has unique markings that identify the time and place of the Lapita people who made them. The distinctive, intricate style of the pot rims above, for example, was replaced in later years by plainer decorations.

local man Matthew David, who has been nicknamed 'Pang Pang's historian' for his knowledge of the area. "We didn't know that the Lapita people came here until [researchers] told us."

The digging is slow and meticulous, but steady progress is being made. In addition to the pottery pieces, the team have so far unearthed shells, coral and animal bones – including some from an ancient giant tortoise that an Australian team believe was hunted to extinction by the Lapita, as published in *Scientific Reports* in 2016.

A new mound containing piles of limestone rocks has excited the researchers, as such stone piles are known to mark Lapita burial sites. If human remains are found at Pang Pang, it could lead to a major archaeological breakthrough.

The landmark discovery

In 2003 in Teouma, a site close to Port Vila in Efate's south, quarrying work uncovered one of the Pacific's oldest graves, containing dozens of individual Lapita remains.

Thanks to the find, not only were French and Australian archaeologists able to document ancient Lapita burial practices – which included the ceremonial removal of skulls from decomposed corpses – but an Australian/US/UK team was also able to use DNA samples to confirm Lapita's lineage out of Taiwan and other islands in Southeast Asia.

"We're still analysing some of the things we found there," Willie says.

Although it's unclear if Pang Pang will yield such pivotal relics, the dig has already acquired historical significance. The excavation marks the first time that indigenous archaeologists of Vanuatu have discovered a Lapita site. Lucas Sarvanu – Vanuatu's only other formally educated archaeologist, who, like Willie, works at the Vanuatu Cultural Centre – made the discovery after he and colleague Iarawai Philip surveyed the area last year. The young archaeologist is gregarious and quick to laugh. He was inspired to become an archaeologist after watching Indiana Jones as a child, and his ambitions have taken him from Vanuatu to the University of New Caledonia, and most recently – thanks to a French government sponsorship – to the Sorbonne University in Paris where he earned his archaeology degree.

"We came to Pang Pang and chatted to the community, especially the chief, old Chief [Tarpuelepul] David, who told us about some of the customary stories," Lucas explains.

After this conversation, they were allowed to walk through the nearby area with the chief's son and some other young villagers.

"This survey was really fruitful because at the end of it, we found all these mounds," Sarvanu says. "These mounds are not natural ... Basically it was a place where our ancestors used to throw away their rubbish. Over hundreds of years, this rubbish piles up until it becomes a big mound that today we can look into."

Cultural connection

Sarvanu and Willie are part of a new generation of Pacific islander graduate archaeologists specialising in Lapita. In Vanuatu, as in many Pacific islands, the majority of recorded archaeological science has been done by foreigners.

This was particularly true before the country's independence in 1980, when foreign scientists working under colonial governments were able to freely enter villages, at times despite protests from locals.

(POT SHERDS ABOVE)

Edson Willie (above left) and Lucas Sarvanu (above right) are Vanuatu's only formally trained archaeologists, but both acknowledge that there are many locals with archaeological skills and knowledge – just without a Western degree.

"Before 1980, people here didn't have power, so foreigners could come inside any community," Willie says.

This history is not lost on a new generation of Western archaeologists. Over lunch at Pang Pang village, the young ANU students discuss the case of Roi Mata, a Vanuatu chief whose grave was uncovered by French archaeologist Jose Garanger almost six decades ago. According to surveys conducted when the site was nominated as a UNESCO World Heritage Site, there was "widespread dissatisfaction" from local villagers about the excavations, which were thought to offend the ancient chief's spirit and led to the regrowth of vegetation around the site (the villagers believe the grave was once so sacred plants were unable to grow there).

They see the tale as a warning, and pledge to always collaborate with local communities, as they are doing in Pang Pang. Such an approach is now mandated in Vanuatu, with all researchers obligated by law to work with the VKS to undertake any studies in the country.

"Archaeology is a field where we go into areas that are considered taboo, for instance we have to touch human remains or dig up graves," Willie says. "Archaeologists must have a respect for culture ... a community must say yes before we go inside, and if they say no then it's up to us at the Cultural Centre to negotiate a road forward."

"My aspiration is that the people from this country are the ones learning and researching about our history ... because it shows that we have pride in ourselves."

There's still a long way to go before local scientists can conduct research independent of foreign institutions. Vanuatu's national university has only two recognised science courses – in environmental and social sciences – and to study archaeology or any other fields, students rely on international scholarships.

"We are letting outsiders write our history, which is not too good," Willie says. "My aspiration is that the people from this country are the ones learning and researching about our history ... because it shows that we have pride in ourselves, that we're not just looking at foreign systems but can look at our own traditions.

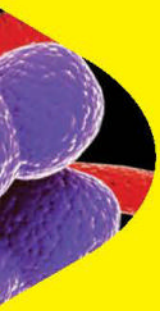
"It reminds me of a saying from Tanna Island – we're standing on the back of a turtle, while asking others where the turtle is."

Sarvanu agrees, saying "Vanuatu must produce more local archaeologists". But he also knows being a Vanuatu-born archaeologist at this point in history, where there is so much still to be discovered, has afforded him an immense privilege.

"Lapita is the pinnacle of Pacific archaeological research," he says. "Imagine, you dig and you uncover a Lapita pot, and then you have to tell yourself 'the last person who touched this pot did that 3,000 years ago' and here you are touching it again. There are no words for that feeling."

PRIANKA SRINIVASAN is a reporter and photographer specialising in the Pacific.

(POT) *OCEANIC EXPLORATIONS: LAPITA AND WESTERN PACIFIC SETTLEMENT*, BY STUART BEDFORD, CHRISTOPHE SAND AND SEAN P. CONNAUGHTON



Rebelling against resistance

Antimicrobial resistance poses a grave threat to public health, and scientists are looking for new ways to combat the rise of superbugs. **Manuela Callari** reports on the vanguard of current research, from the high-tech to the unexpectedly ancient.

Amy Cain gets a little paranoid whenever she prepares chicken for tea. She washes chopping boards and knives twice and makes sure there's no cross-contamination happening. "Food preparation is the one thing I get funny about," she says.

Raw chicken can be contaminated with *Campylobacter* spp, *Clostridium perfringens* and *Salmonella* spp. The latter is the bug that causes typhoid, the infection Cain was fighting in 2007 while pondering what subject area she should take for her PhD. She chose food-borne infections. "I was like, I'm gonna get you," she recalls.

Now an associate professor at Macquarie University, Sydney, Cain continues to peruse pesky bugs. Her current favourite is *Acinetobacter baumannii*, a superbug – a bacterium that survives currently available antibiotics. Declared one of the top three critical pathogens by the WHO, *A. baumannii* is so tough that it can live undisturbed on surfaces for months. Cain has isolated and desiccated it completely – rehydrated a year later, it was able to infect mice. It attaches to medical devices such as ventilator tubes and intravenous catheters and is responsible for up to 20% of infections in intensive care units.

Cain and thousands of other scientists around the globe want to understand more about the world of superbugs to find better ways to protect us from one of our biggest unsolved health threats. Superbugs are everywhere. They've been found in playgrounds, farms, drinking water, sausages and seagulls, riding tiny plastic fibres in the ocean, in Finnish paper mills, 300 metres underground in an isolated cave in New Mexico and even in the Arctic.

Our immune system can usually keep them at bay. But in hospitals, drug-resistant bacteria become a serious issue. This is where the six scariest pathogens – *Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *A. baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* spp, collectively known as ESKAPE – are found. Hospitals are also where sick, debilitated, wounded and immunocompromised people are – and they're the perfect hosts.

"[Bacteria] are extremely opportunistic," Cain says. "We have a rule in the lab: if you have a burn or even a small cut, you can't come in at all, because they just find you."

A study published in *The Lancet* in 2022 examined 494 million patient records and estimated that antimicrobial resistance (AMR) killed 1.27 million people in 2019 and played a role in another five million deaths – meaning superbugs killed more people that year than AIDS and malaria together. The researchers predicted that by 2050, 10 million people will die every year from AMR complications.

In Australia, surveillance data are patchy, but a recent report found that AMR could kill more than 5000 people yearly within the next decade.

"It's a much bigger issue than most people realise," says Branwen Morgan, the Minimising Antimicrobial Resistance mission lead at CSIRO.

If antibiotics fail, even a routine surgery will become life-threatening; forget organ transplants and caesarean births. According to scientists, AMR is the biggest health crisis we'll experience this century. "If nothing's done, we're going to see an ever-increasing rate of drug-resistant infections," Morgan says.

Branwen Morgan, Minimising Antimicrobial Resistance mission lead at CSIRO.

HOW DID WE GET INTO THIS MESS?

Bacteria are clever beasts. Like all living things, they've evolved to deal with changes and pressures in their environments and sometimes evolve a super trait in their genes that gives them a competitive edge in survival – like the ability to resist antibiotics. These superbugs then pass on their super genes to their offspring. They also swap and share their super genes with other species. "They're really talented at changing themselves and borrowing help from their friends," says Cain.

The first antibiotic, penicillin, was discovered by Alexander Fleming in 1928. It wasn't widely available until the 1940s, when it was used to treat infections caused by bacteria during World War II. By 1942 the first cases of of penicillin resistance had already been reported. In the 1950s and 1960s, antibiotics were heavily overprescribed, including for viral infections on which they had no effect.

The more often bacteria are exposed to antibiotics, the greater the opportunity to develop ways to survive and grow in their presence. Compared to most European countries, Australia still has a higher antibiotic prescribing rate, with nearly 25% of prescriptions being given without evidence of benefit.

Over the past three years, AMR has spiked globally; the COVID-19 pandemic has likely played a role. Studies found that 60–70% of hospitalised COVID patients received antibiotics, but less than 10% had primary or secondary bacterial infections, so most antibiotics used were unnecessary.

AMR killed 1.27 million people in 2019 and played a role in another five million deaths – superbugs killed more people than AIDS and malaria together.

Amy Cain, associate professor at Macquarie University, Sydney.

In hospitals, the high use of antibiotics and disinfectants puts bacteria under so much pressure that those who survive, thrive.

"They're so smart. They've been doing this for a long time – they will become resistant to anything you throw at them," Cain says.

Not only are current antibiotics becoming increasingly ineffective, there are no new antibiotics in the pipeline. The development of new antibiotics is an expensive process, with low profit margins: antibiotics are typically used for short periods of time, and pharmaceutical companies are increasingly interested in developing drugs that treat chronic disease. The last time scientists discovered a novel class of antibiotics that would eventually make it to market was in 1984. Daptomycin was approved by the US FDA (Food and Drug Administration) in 2003, nearly two decades after its discovery.

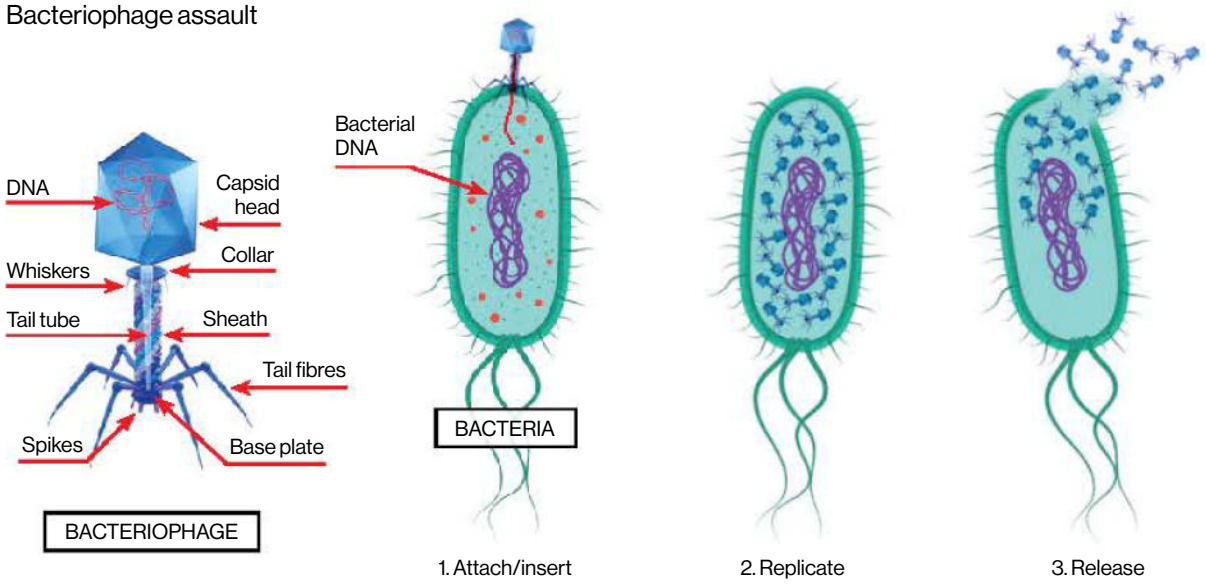
Now scientists are racing to find alternatives.

MAKING ALLIES FROM TINY VIRUSES

Fernando Gordillo Altamirano spends lots of his time searching through crap. Literally.

Every month, he receives a litre of fresh raw sewage from Melbourne Water from which he fishes bacteriophages. "It's not the prettiest part of my job," he admits – but it is a necessary one.

FAR LEFT: THE CAIN LAB. PREVIOUS SPREAD, CLOCKWISE FROM TOP LEFT: ALISSA ECKERT; BSIP; ROGER HARRIS; ALFRED PASIEKA; ALISSA ECKERT; JUSUN / GETTY IMAGES



Bacteriophages land on a suitable receptor on a bacterial cell wall and latch onto their victim, driving their tail through the cell's membrane and injecting their genome. They turn the bacterium into a factory to multiply, until they burst out, killing their host.

Bacteriophages – from the Greek "bacteria devourer", also known as simply phages – are the most abundant organisms on Earth. They're in sewage in big numbers. "Phages live where their prey live," says Gordillo Altamirano, a medical doctor and microbiologist at Monash University.

Phages are tiny viruses with an icosahedral head that contains their genome and a protein tail. They have been at odds with bacteria for as long as life has existed on Earth (see Bacteriophage assault, above).

Gordillo Altamirano uses superbugs as bait to fish for the right phage from his sewage samples. "It's a process of luck," he says. "But if it's there, it's going to bite." The predator phage infects the bacteria and multiplies.

These picky viruses infect neither mammalian cells nor the rest of the bacteria in the microbiome, avoiding the nasty side effects of antibiotics. But this specificity makes phage therapy extremely personalised and difficult to scale up.

As "living" antibiotics, phages have several advantages and pitfalls. Because they can replicate quickly, initial dosages can be relatively low. But they won't eradicate bacteria completely, because their survival depends on them. Unlike chemical antibiotics, they co-evolve with their prey, blunting a bacterium's ability to develop resistance, at least in theory. In about half of patients, bacteria evolve to survive and the phage treatment becomes less effective, says Jean-Paul Pirnay, head of the Laboratory for Molecular and Cellular Technology (LabMCT) in Queen Astrid Military Hospital, Belgium. But evolutionary pressure comes at a cost: bacteria can lose virulence or antibiotic resistance in the process.

Fernando Gordillo Altamirano, medical doctor and microbiologist at Monash University, Melbourne.

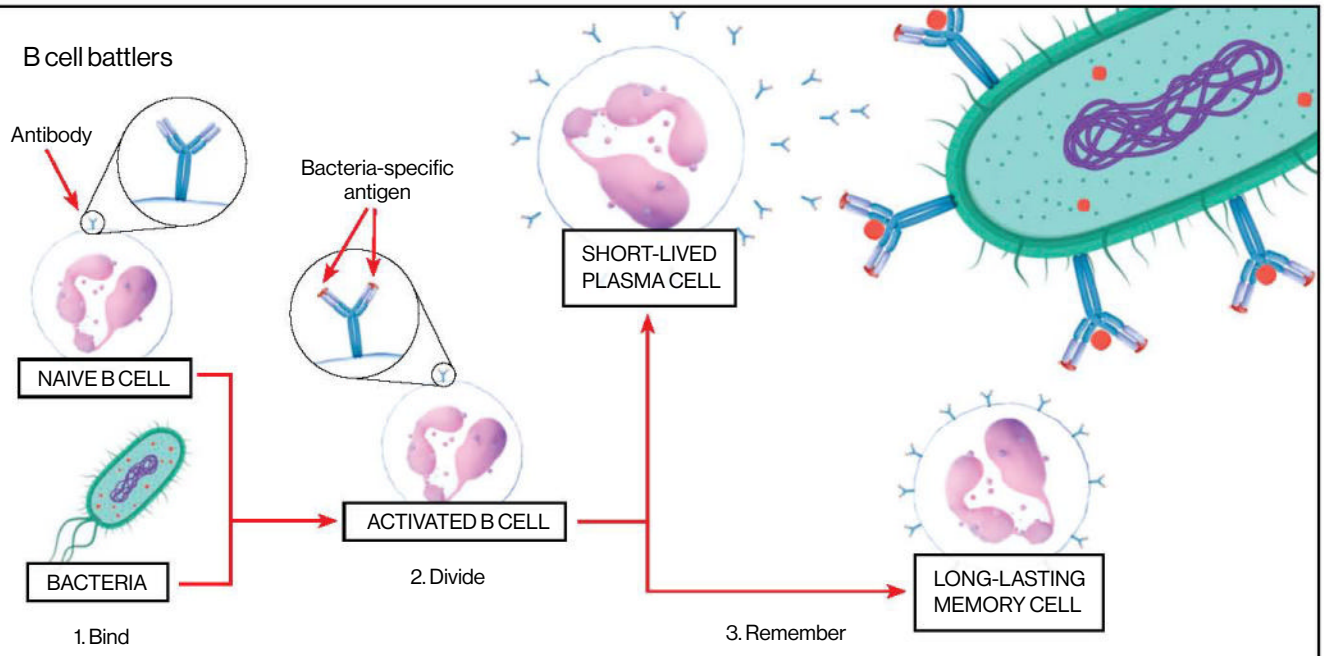
Phages were discovered over 100 years ago when Felix d'Herelle, a French-Canadian microbiologist at the Pasteur Institute in Paris, realised their potential to treat bacterial infections. In 1917, d'Herelle was studying a cholera outbreak when he noticed that some of the patients' stool samples contained clear spots, which he called plaques.

D'Herelle hypothesised that the plaques were caused by a virus that was attacking the cholera bacteria. He added clear spots from the samples to cultures of cholera bacteria, which quickly died.

D'Herelle then went on to isolate and culture the bacteriophage, and he showed that it could be used to treat cholera infections in mice. In 1919, he was the first to use phages to cure a 12-year-old boy with severe dysentery. But within a few decades of their discovery, they were largely abandoned in favour of antibiotics, at least in the Western world. One of d'Herelle's colleagues, a young Georgian scientist named George Eliava, returned home to found the institute that now bears his name.

Today, the Eliava Foundation's Phage Therapy Centre treats thousands of Georgians every year, and hundreds of foreigners from 84 countries, including Australia. Most patients buy phage cocktails off the shelf of the centre's pharmacy to treat non-resistant infections. Those with tougher bugs are treated with personalised therapies.

ILLUSTRATION: GREG BARTON



When a "naïve" B cell encounters a pathogen, it binds to it with its antibody receptor. If the binding is strong enough, the B cell will be activated and begin to divide to produce more B cells – all specific to the same pathogen, and able to produce antibodies against it. B cells also help to remember pathogens the body has been exposed to in the past, allowing for a more rapid immune response if the same pathogen is encountered again.

Despite the encouraging anecdotal evidence from Georgia, in Australia, the EU and the US, phage therapy is only available on compassionate grounds. "It's only a very, very small proportion of patients that would qualify," says Gordillo Altamiro.

Phage Australia, a national network of phage researchers and clinician scientists, is running a phase I clinical trial to assess phages' safety. Around the world, 11 other studies are currently recruiting. Biotech companies are pushing into this space, and the market for phage therapies is predicted to grow 17% by 2030 to approximately $84 million annually. But phage therapy will not be widely available until large, randomised clinical trials are completed – a process likely to take years.

There are still plenty of questions left to answer. Scientists need to figure out the immune system's response to phages. Some people seem to produce antibodies that quickly neutralise them; others, not at all. Whether to use phages before, together or after a standard course of antibiotics is still debated.

Pirnay envisions a future where bacterial DNA is extracted from a swab and sent to a secured server where complex AI-based algorithms predict the genome sequence of the phage most likely to kill the bacteria. The phage genome is then sent to a 3D bioprinter, which produces synthetic phages ready to use within an hour of the swab being taken.

But in the here and now, microbiologists are using next-gen technology to engineer phages to target superbugs and deliver a lethal payload.

Jean-Paul Pirnay, head of the Laboratory for Molecular and Cellular Technology (LabMCT) in Queen Astrid Military Hospital, Belgium.

GENOMIC SCISSORS

Just like humans, bacteria can get sick from a viral infection. CRISPR/Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats – CRISPR/associated protein 9) is a system bacteria use to protect themselves from viruses. The Cas9 enzyme is guided to the viral DNA by a short RNA molecule, and cuts the viral DNA in a targeted location. The bacteria can then destroy the virus.

Now scientists are loading phages with CRISPR/Cas9 to turn that bacterium machinery against itself. "We can feed bacteria with short synthetic sequences programmed to cut a specific DNA sequence," says David Sünderhauf, a microbiologist at the University of Exeter, UK.

Sünderhauf's research targets antibiotic plasmids – circular strands of bacterial DNA where antibiotic resistance is encoded. CRISPR/Cas9 can break these plasmids apart, making the bacteria vulnerable to antibiotics again.

There are several advantages to targeting antibiotic plasmids. They are found in a broad range of drug-resistant bacteria but not bacteria in the microbiome or mammalian cells, which remain unaffected. If a superbug shares its antibiotic plasmids with another, the latter loses resistance – a highly valuable trait to treat antibiotic resistance

ILLUSTRATION: GREG BARTON

in the environment, such as wastewater treatment plants, where these bacterial double agents could nullify a great number of superbugs in one sweep.

While gene editing shows promise in pre-clinical studies, many hurdles still exist. The greatest is resistance. "We know that anti-CRISPR proteins exist," Sünderhauf says.

Bacteria can evolve CRISPR/Cas9 resistance by acquiring point mutations in the DNA sequence that are targeted by the guide RNA. These mutations can prevent the guide RNA from binding to the DNA, or stop the Cas9 enzyme from cutting the DNA at that location. For example, a bacteria could acquire a point mutation that changes one of the nucleotides in the DNA sequence that is targeted by the guide RNA. This would prevent the guide RNA from binding to the DNA, and the Cas9 enzyme would not be able to cut the DNA at that location.

One way to overcome this is by delivering two different editing tools targeting the same gene in two regions, because it is much less likely that two point mutations will occur simultaneously.

Another challenge is associated with microbial community complexity. Bacteria like to live in colonies that contain thousands of species, and nuances in resistance genes can be found even within single species. It is also difficult to predict how a community will respond to such changes. If a strain is removed from a population or its metabolism is affected, this may allow other, potentially more problematic species to outgrow it.

BIOLOGICAL THERAPY

Some scientists are looking for allies within our own immune system.

We are born with trillions of B cells, a type of white blood cell responsible for producing antibodies. Antibodies are proteins that bind to specific antigens (molecules that are found on the surface of pathogens, such as bacteria and viruses). When an antibody binds to an antigen, it can help to neutralise the pathogen or mark it for destruction by other immune cells.

"We have more types of B cells than stars in the Milky Way galaxy," says Natalia Freund, a microbiologist at Tel Aviv University, Israel.

B cells are all "naive" until they encounter the targeted pathogen (see "B cell battlers", opposite). Scientists have learned to identify such monoclonal antibodies (an antibody that targets a specific antigen), isolate them and reproduce them in large quantities. Injected into a patient, monoclonal antibodies travel to their target, activate the immune system and attack that target just as antibodies produced by a person's own B cells would. "We can give a patient an antibody that targets exactly what we want to stop," says Freund.

David Sünderhauf, microbiologist and postdoctoral research fellow at the University of Exeter, UK.

Monoclonal antibodies are already used in immunotherapy to treat cancer and autoimmune diseases, but Freund wants to unleash them against bacteria. She has isolated monoclonal antibodies that hinder the growth of *Mycobacterium tuberculosis* (Mtb) in mice. Mtb is a highly infectious bacterium that travels through the air and is well adapted to humans. Tuberculosis (TB) is often latent and asymptomatic, so it can jump from person to person undetected. It affects 10 million people every year, killing 1.5 million. Recently, multi-drug-resistant forms have emerged, infecting half a million people yearly. "Once we run out of antibiotics, TB will be a major problem," says Freund.

Mtb expresses almost 4000 proteins on its membrane, and identifying the one protein antibodies latch onto was laborious. Freund used Mtb as bait and went fishing in a bowl of B cells from patients who had recovered from TB to catch reactive B cells. She pinpointed a phosphate pump protein on the Mbt cell wall, which supplies energy to the bacterium and is highly specific and exists across all tuberculosis strains. She isolated and sequenced the monoclonal antibodies that blocked the action of the pump, then grew more of them.

Monoclonal antibodies are already used in immunotherapy to treat cancer and autoimmune diseases, but Freund wants to unleash them against bacteria.

Tuberculosis-infected mice who received the treatment had a 50% reduction in Mtb growth compared to the control. There is a wide margin for improvement, but the study, published in *Nature Communications*, is an essential proof of concept.

Freund thinks that monoclonal antibodies could be used as adjunctive therapy with antibiotics to treat TB and other bacterial infections. "We are assessing [the treatment] in various preclinical models, [including] its ability to prevent reactivation [of the latent form] or infection altogether."

Natalia Freund, microbiologist at Tel Aviv University, Israel.

HONEY: AN OVERLOOKED REMEDY

In the fight against AMR, scientists are rediscovering the antibacterial power of one ancient remedy. Honey has been used as a wound dressing since long before bacteria were discovered. All kinds of honey have some antimicrobial activity: its high sugar content and low pH create an unwelcome environment for microbes.

While that's not enough to treat an infection, some kinds of honey can be powerful antimicrobials. Some bees add an enzyme called glucose oxidase to their honey, which – when it comes in contact with moisture, for example from wound fluid – converts sugar into hydrogen peroxide, a weak bleach that kills bacteria. Many types of Australian honey are high in glucose oxidase.

But then, some honey has extra power. The nectar of the Mānuka flower (*Leptospermum scoparium*) contains the compound dihydroxyacetone (DHA). Over time, DHA converts into another chemical with potent antimicrobial traits, methylglyoxal (MGO). While the most famous Mānuka honey comes from New Zealand, over 80 Leptospermum species grow in Australia, including *L. scoparium*.

Nural Cokcetin, a microbiologist at the University of Technology Sydney, tested 45 of them and found that a third had high activity – some even higher than Mānuka. In the lab, MGO-rich honey kills antibiotic-resistant and susceptible bugs alike and doesn't seem to trigger resistance.

"We are unlikely to see resistance anytime soon. Honey has already been used for thousands of years, and there's no resistance," says Cokcetin.

Why isn't exactly clear. Besides sugars, glucose oxidase and MGO, honey contains a whole bunch of phenolic acids and antimicrobial peptides, from either the bees or the flowers they feed on. Over 200 components orchestrate attacks on the bacteria; the bug struggles to fight them all off at once.

Nural Cokcetin, microbiologist at the University of Technology Sydney.

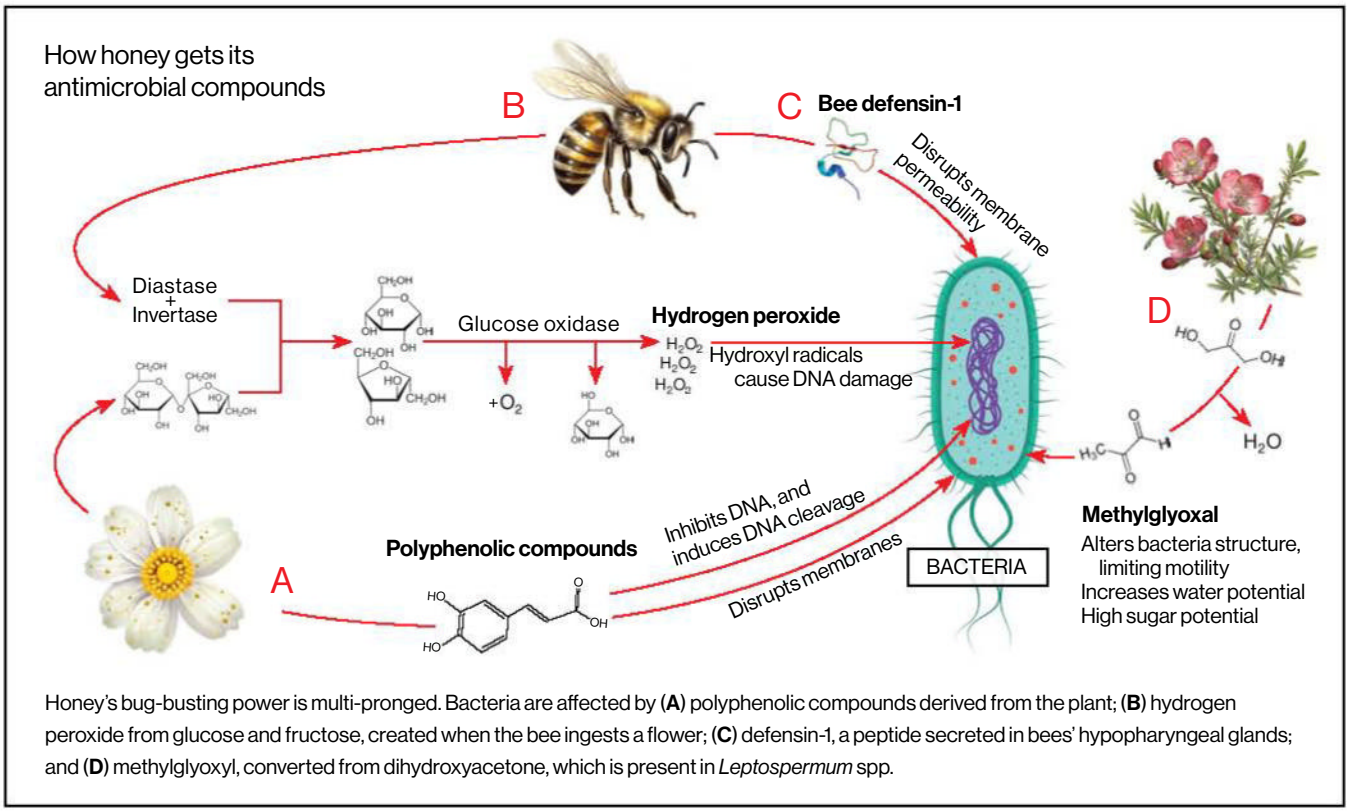
Honey-based ointment, alginate dressing, gel pads, adhesive dressings, nasal and throat sprays are widely available at pharmacies. But GPs often overlook them in favour of modern antibiotics. "People look at honey as an alternative medicine. But if we use it before [the infection] becomes a huge problem, we can save those antibiotics for when we really, really need them," says Cokcetin.

PREVENTING INFECTION ALTOGETHER

Treating antibiotic-resistant bacterial infections poses challenges for scientists and doctors, so perhaps the solution lies much earlier in the process.

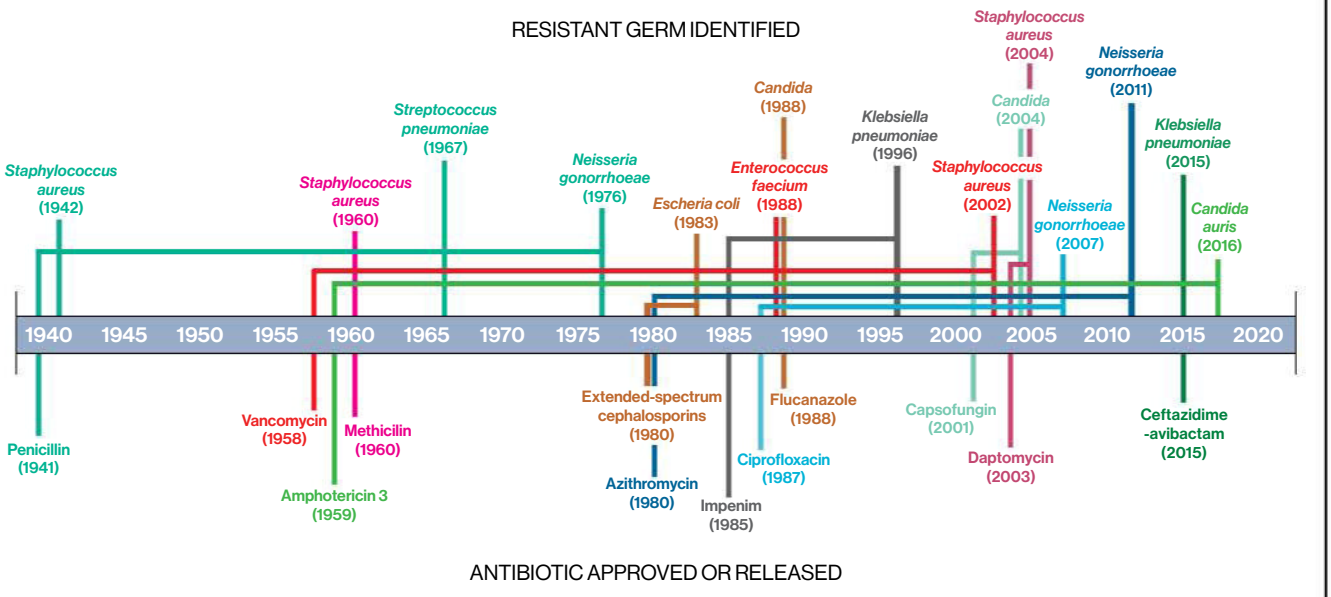
Bacterial vaccines have a long history, dating back to 1896, when Almroth Wright developed the typhoid vaccine: a live, attenuated strain of the *Salmonella typhi* bacteria. Like viral vaccines, bacterial vaccines target specific antigens on the microbial cell wall, initiating an immune response that helps the body recognise and neutralise these pathogens. "Selecting good candidate vaccine antigens can be difficult," says Kate Seib, a professor of microbiology at Griffith University, in Queensland.

Advances in genomics have made the task easier. Scientists can analyse a bacterium's genome and examine potential antigens to identify the ones that are exposed on its membrane and accessible to the immune system.



Honey's bug-busting power is multi-pronged. Bacteria are affected by (**A**) polyphenolic compounds derived from the plant; (**B**) hydrogen peroxide from glucose and fructose, created when the bee ingests a flower; (**C**) defensin-1, a peptide secreted in bees' hypopharyngeal glands; and (**D**) methylglyoxyl, converted from dihydroxyacetone, which is present in *Leptospermum* spp.

ILLUSTRATION: GREG BARTON



Before antibiotics, more than half of all deaths could be attributed to bacterial infections. The discovery of antimicrobial substances has increased the average human lifespan by one to two decades – but bacteria have developed resistance in response, rendering antibiotics increasingly ineffective. Few new ones are in the pipeline, partly because profit margins aren't high enough for pharmaceutical companies.

Since bacteria can mutate easily, scientists must identify antigens that remain constant over time and across strains. Many bacterial vaccines are multi-component: they target several antigens and can provide broader coverage against different strains, reducing the likelihood of bacterial escape through simultaneous mutation of all antigens.

There are several bacterial vaccines in the pipeline. Seib is running a phase I clinical trial of a vaccine against *Neisseria gonorrhea*, a bacterium transmitted through unprotected sex that has developed resistance to all but one class of antibiotics. It is well-adapted to humans and excellent at evading our immune system.

Gonorrhea cases are most prevalent in low- and middle-income countries, where access to antibiotics can be challenging. "In some parts of Africa, there's not a clinic on the street corner," says Seib. "Vaccines can prevent some of these issues."

Vaccines against four of the WHO's priority pathogens – *Salmonella*, *Streptococcus pneumoniae*, *Haemophilus influenzae* type b, and Mtb – exist, but are not equally distributed worldwide. The *S. pneumoniae* vaccine, for example, has dramatically reduced mortality in the US and Europe but is not widely available in sub-Saharan Africa, where most cases are detected. "[Equal distribution of vaccines] is not something that needs to happen in the future. It's something that needs to happen now," says Pilar Garcia-Vello, an AMR scientist and former AMR global coordinator at WHO.

Kate Seib, professor of microbiology at Griffith University, Brisbane.

Pilar Garcia-Vello, AMR scientist and former AMR global coordinator at WHO.

She says vaccine uptake is essential in all parts of the world and across society. "If there is herd immunity, there is a decrease in the circulation of pathogens. That will make a huge impact."

TO EACH THEIR OWN

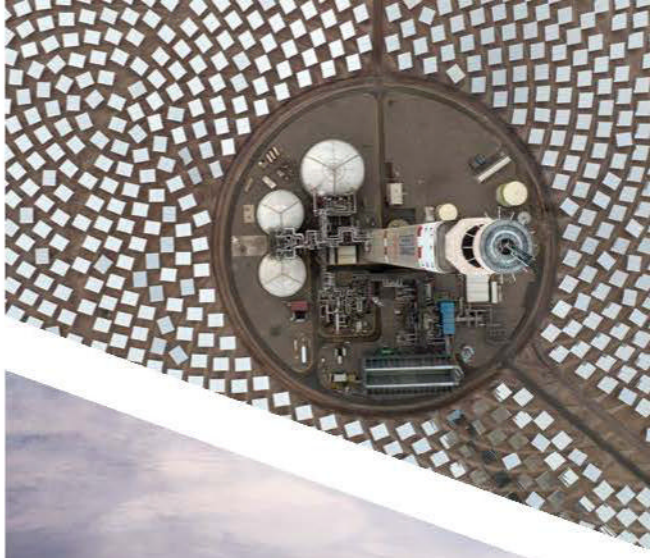
None of the people working on AMR thinks one single therapy will replace the use of antibiotics. Instead, each will be essential in the AMR toolbox.

The amount of research in the AMR field is somewhat reassuring, yet many questions remain unanswered. One common problem for many novel therapies is the regulatory framework around which they should be produced and marketed. Licensing viruses, gene-editing tools or animal products as medicines can be challenging.

Cain, the superbugs expert, says everyone has their part to play. "A collaborative, multisectoral and transdisciplinary approach is 100% the way to go," she says. "When half of the world's population doesn't have access to flushing toilets or proper sanitation, it doesn't matter how well one country is doing. If resistance arises anywhere in the world, it will spread anywhere else."

MANUELA CALLARI is a science and medical journalist. Her last story, on death, appeared in Issue 92.

ILLUSTRATION: GREG BARTON



FUTURE POSSIBLE

In 2006 we asked scientists to predict life in 2020. **Bron Willis** reports on how those predictions stack up – and has another group of scientists look ahead to 2040.

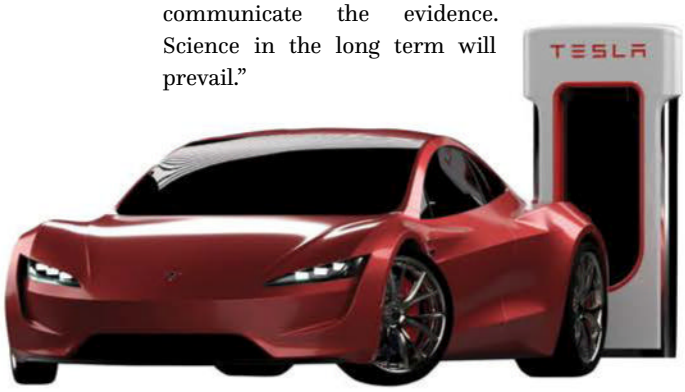
Humanity has a special talent for imagining the future – encompassing both our deepest fears and our loftiest dreams. Hollywood is particularly good it. Think of Stanley Kubrick's 1968 existential conversation between an astronaut and his computer in *2001: A Space Odyssey*; the 2013 film *Her*, which explored the relationship between a man and his virtual assistant; and 2008's post-apocalyptic *Wall-E*, which showed us an uninhabitable planet Earth 700 years from now, to name just a few.

Here at *Cosmos*, we like to imagine the future too, but with a little more science to guide us: in 2006, our feature story "Life in 2020" hit the stands in Issue 9, taking a look at what life then might be like. The topics we discussed bore an uncanny resemblance to those explored by Hollywood but with a little more grounding.

As *Cosmos* celebrates 100 issues, we look at what science predicted for the 2020s: what we got right, what we got wrong – and what we still don't know. The questions, somewhat depressingly, are largely the same. How long can our planet continue to support us? How will artificial intelligence change our lives and will that change benefit or undo us? Is there life in the Solar System, or further afield – or are we all alone?

Perhaps the greatest question for you, the *Cosmos* reader, is the role of science in all this rapid technological, political and social change. Dr Alan Finkel, Australia's chief scientist from 2016 to 2020, remains hopeful.

"The role of science goes up and down in society," says Finkel. "2020 was definitely a good year for science: political leaders and society turned to medical science in particular during COVID. And now in 2023 you're starting to see it collapse again. But science just keeps doing what it should do, which is – do the research, find the evidence and communicate the evidence. Science in the long term will prevail."



Big movers since 2006 (clockwise from above): the Higgs Boson, sustainable energy, lithium production, electric cars.

CLOCKWISE FROM TOP LEFT: MARK GARLICK; JOHN MOORE; WITTHAYA PRASONGSIN; SKYHOBO / GETTY IMAGES. (TESLA) MIKE MAREEN / SHUTTERSTOCK

The 2020 scorecard

In 2006, writer Robin McKie asked astrophysicists, climatologists, oncologists, ecologists, robotics specialists and renewable energy experts what they thought life in 2020 would be like. There were some big predictions ("by 2020 we will have good evidence that we have neighbours somewhere in the galaxy"), some that fell differently to prophecy ("intelligent clothes" made from "special fabrics, fitted with monitors that will study our health throughout the day, while we sleep, work and exercise") and others that landed exactly as forecast.

ENERGY AND ROBOTS

If a reduction in carbon emissions is key to reducing the climate disaster's impact and biodiversity loss, then the development of clean energy is critical. For Alan Finkel, it's a passion.

"In 2006, we were only very hesitantly around the world beginning the deployment of solar and wind electricity generation, and batteries for utility storage."

Since then, geometric growth from that small base has continued such that now in 2023 we're still seeing growth rates per annum consistent with a fourfold increase per decade, according to Finkel.

"If we can maintain that for the rest of this decade, we'll start to see sufficient solar and wind electricity entering the global energy supply to actually turn around at the rate that oil, coal and gas continue to grow."

Finkel also points to an "explosion of electric vehicles", with battery electric vehicles taking 15% of the world sales in 2022, and rapid growth continuing this year.

"Machines are good at the things we find hard, but bad at the things we find easy. Stacking the dishwasher [is] remarkably hard for computers."

There were high hopes in 2006 for relief from the daily grind of domestic life. Back then, we predicted that "home robots [would] be the next consumer 'must have' by 2020 when they [would] have become as ubiquitous as personal computers today". Sadly, a one-stop solution for housework remains a dream.

"Robots doing the housework hasn't happened in the way that perhaps people expected or at least Hollywood led us to expect," says Toby Walsh, Professor of Artificial Intelligence at the University of New South Wales. Rather, development has jumped ahead in discrete areas and not others.

"Machines are good at the things we find hard, but bad at the things we find easy," says Walsh (referring to "Moravec's paradox" observed by US robotics expert Hans Moravec in the 1980s.) "It turns out, stacking the dishwasher might be easy for humans, but remarkably hard for computers," Walsh says. Vacuuming the floor, however, is a breeze for robots (although arguably less breezy for some of their older or less technologically savvy owners). "The most common robot in the world is the robot vacuum cleaner," says Walsh.

One estimate suggests there were 17.3 million robo-vacs in service around the globe in 2021.

Robots have also changed some consumer experiences and industries immensely: checking in at an airport (whether for better or worse), our mines ("Australia has the most automated mines on the planet," says Walsh) and our warehouses, which are now designed specifically to increase the efficiency of robots picking and packing products.

But Walsh differentiates between AI, computers and robots.

"We've got computers in our hands now that are faster than the fastest supercomputers we had 50 years ago," he says. "But with robots, we've never had those exponential returns. It's still a hard thing to design a robot mechanically.

"We've certainly been impressed by the developments in AI in the last 15 years. I think most of us have been surprised even by some of the speeds of recent progress in terms of giving computers fluency and language. But equally, we're still missing some fundamental things – they're not deeply understanding the language of reasoning."

But there's one application of AI that has not borne out as anticipated, according to Finkel.

"I think the vast majority of people in around 2010 would have thought that by now we'd have fully autonomous vehicles but they're a rarity at the moment," he says. "It turns out that it's really, really hard to do, especially while there are still people-driven cars on the road."

SOLAR SOLUTIONS

Number of solar panel systems on Australian homes:

2006: 4,643

2023: 3,523,729

CLIMATE

The most predictable yet still alarming result, perhaps, is just how right the climate prognosis was, according to climate scientist and former Chief Commissioner of the Climate Commission, Professor Tim Flannery. "We're on the upper edge of our expectations, in terms of emissions trajectory and the flow-on from that," he says. "The projections that we had back in 2006 were for outcomes not quite so catastrophic as what we're seeing now."

The surprise, Flannery says, is just how quickly we've got here: "Parts per million in the atmosphere [of CO_2 – we hit 424 in 2023, up from 315 in 1960 according to the NOAA], the accumulating heat in the ocean, the nearness of some of the tipping points – these are all of grave concern.

"Since *Cosmos* interviewed me in 2006, humans have emitted more than a third of all of the greenhouse gases that we've ever emitted in our history on the planet."

Back in 2006, Flannery said: "It's now too late to avoid changing our world. But we still have time, if good policy is implemented, to avoid disaster." Flannery's prediction for a changing world has certainly come to pass. In August 2023 the World Meteorological Organization confirmed that July 2023's global average temperature was "the highest on record for any month".

But have we avoided disaster in the past 15 years? Due to the delay in the impact of emissions, says Flannery, we don't know yet.

"Some trends are absolutely embedded now – we've emitted enough pollution that we know for the next 20 years, things are going to keep getting worse, almost no matter what we do. Just how much worse is the question."

James Lovelock, the late British scientist,

FROM FAR LEFT: POLYSOLAR.HOLGER LEUE / GETTY IMAGES. NASA. SW_PHOTO / GETTY IMAGES.

futurist and environmentalist, warned in our 2006 article that "for most people on the planet, it will be like living through war. It will be grim."

Most of us would argue that we've not yet been affected by climate refugeeism, but in 2016 the United Nations High Commissioner for Refugees (UNHCR), reported that since 2008 around 21.5 million people per year had been forcibly displaced by weather-related events.

Consider events such as record-breaking 2023 Northern Hemisphere summer heatwaves, Australia's 2019–20 Black Summer bushfires and a recent global litany of record droughts and floods and you could argue this looks a bit like disaster – and for many, might feel a lot like war.

Island nations have been the first to experience population displacement due to rising sea levels. A 2016 paper by Australian researchers found sea levels in the Solomon Islands were rising at a rate three times higher than the global average that year and were "the site of the first sinking islands of the 21st century".

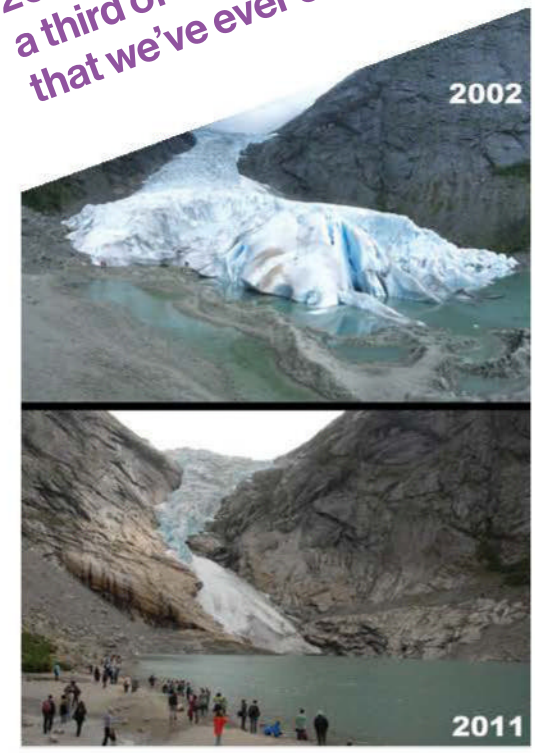
The study identified "five vegetated reef islands that have vanished" and "a further six islands experiencing severe shoreline recession", including two sites where communities were relocated from villages destroyed by shoreline recession.

The solution to avoid an even worse outlook for humanity?

"We've got to do two very difficult things at once," says Flannery.

"We've got to cut our use of fossil fuels and at the same time, we need to draw down CO_2 out of the atmosphere, and sequester it in the rocks. We need to do both of those things simultaneously at a very large scale. And we need to get really serious about restoring our forests."

"Since Cosmos interviewed me in 2006, humans have emitted more than a third of all of the greenhouse gases that we've ever emitted in our history."



The future carries a promise of weather extremes, including more wildfires (above) – as this year's Northern Hemisphere summer has proven. Icelandic writer Andri Snær Magnason's poignant ode (opposite) to the Ok Glacier, which was declared dead in 2014, is required reading at glaciers around the world. The Briksdal glacier in Norway (left) is one of many in decline.

ANYONE **OUT THERE?**

Seth Shostak, senior astronomer for the SETI Institute smiles amiably into his screen, recalling his predictions for the "three-horse race" he described in 2006 – our race to find extra-terrestrial life either by Earth-based radio telescopes, planetary probes, or space telescopes. "By the end of the next decade we will have found evidence of extraterrestrial life," said Shostak at the time.

"Those horses are still in there," he says on video call from California. "You know, they were fed a lot of hay to begin with but the race is obviously still going because nobody has won – we still haven't found it. In fact, we haven't found any life in space.

"It's a little surprising. If we talked about this question, even 40 years ago, I'm sure most people would have said that by now we would know. Have we found life on Mars? Well, there's a lot of hardware on Mars, manufactured here on Earth, but it still hasn't found any life."

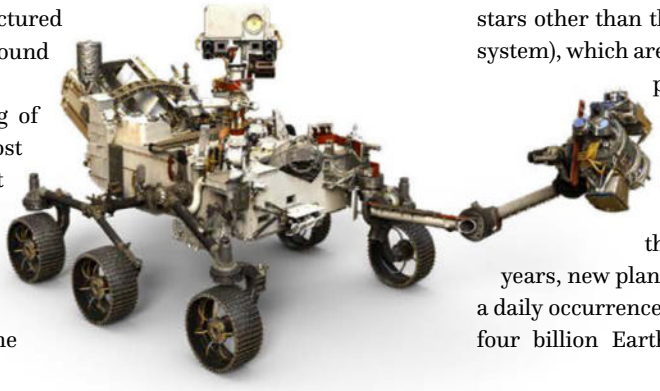
According to Shostak, funding of space exploration is one of the most exciting developments in the past 15 years, and the search for intelligence in the universe has also been reinvigorated by private supporters.

"It's still pretty much the same experiment that it has always been – using big antennas to try and eavesdrop on radio signals," Shostak says.

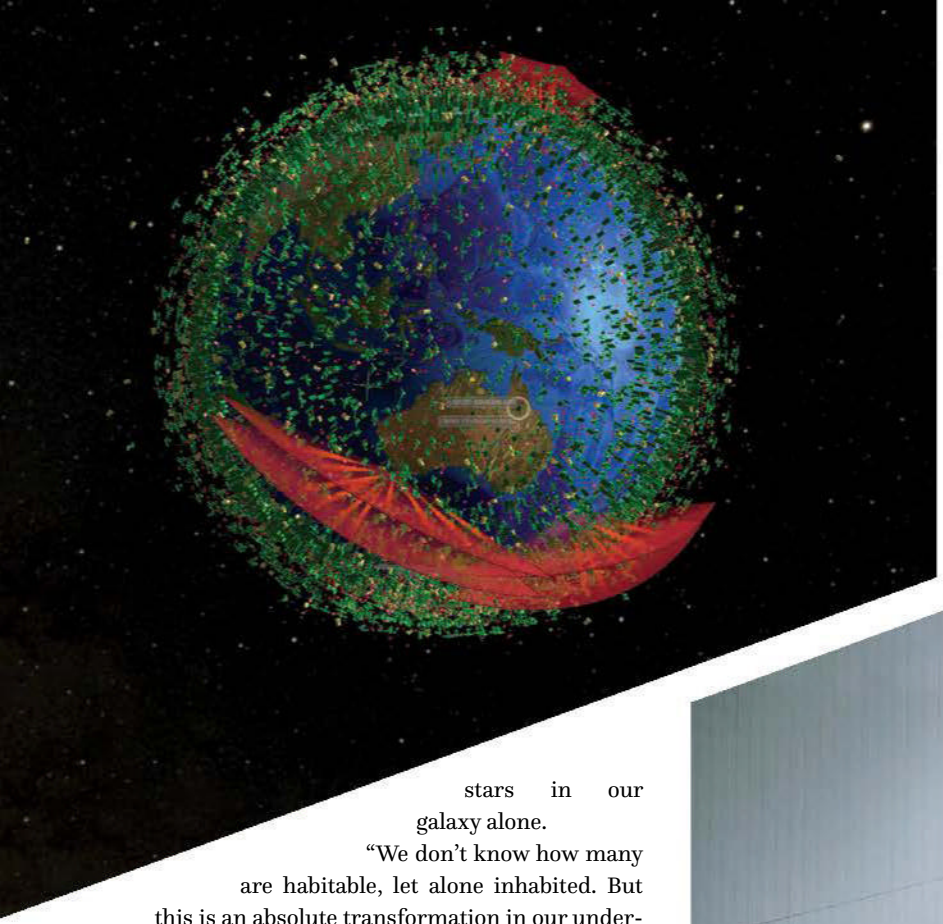
For Professor Alan Duffy, an astrophysicist at Swinburne University of Technology, one of the leaps forward in space exploration since 2006 has been discoveries of exoplanets (planets that orbit stars other than the Sun and outside of our solar system), which are now so commonplace that they pass unnoticed by most.

"The big surprise is that exoplanets are not only theorised and detected, but we have now detected thousands of them," Duffy says. "In the last five years, new planets are being detected almost as a daily occurrence. We can estimate that there are four billion Earth-like worlds around Sun-like

"Exoplanets are not only theorised and detected, but we have now detected thousands. In the last five years, new planets are being detected almost daily."



FROM TOP: NASA, JAMES WEBB SPACE TELESCOPE; MARK GARLICK / GETTY IMAGES



NUMBER OF ACTIVE SATELLITES
2006: 812
2022: 6718

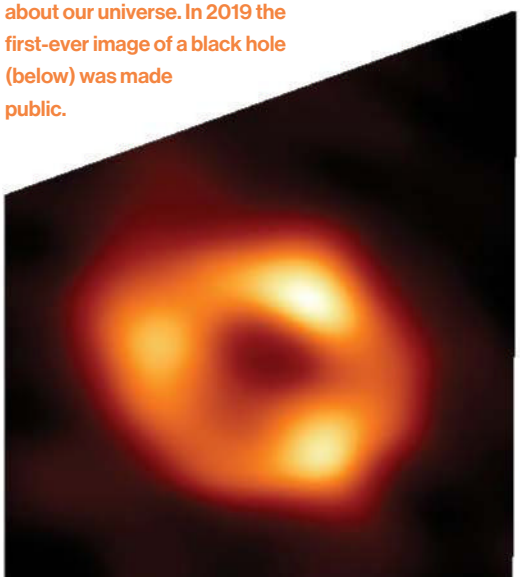
stars in our galaxy alone.

"We don't know how many are habitable, let alone inhabited. But this is an absolute transformation in our understanding of our place in this galaxy."

One of the things that's most surprised Duffy about space exploration in the past 15 years is who's doing it. "We have nations joining the search of the Red Planet that I think would have been unthinkable: the United Arab Emirates, the first Arab nation in history to have a satellite around the planet; India has launched incredible missions. These were new entries that I think would have surprised people, 20 years ago."

"Truly unthinkable" in 2006, according to Duffy, was also the idea that we would have thousands of satellites in orbit "and in particular, that many would be operated by a start-up that was less than 10 years old [SpaceX, which owns Starlink]."

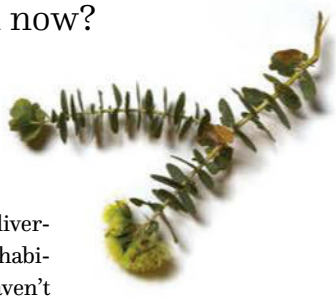
Mars rovers and the James Webb Space telescope (right) have contributed to the rise in knowledge about our universe. In 2019 the first-ever image of a black hole (below) was made public.



FROM TOP: LEO LABS; NASA X2.

Looking forward – life in 2040

Scientists (with the help of a little AI) are adept at making predictions based on measurable data such as ocean temperatures, population growth, cancer mortality and methane levels in an exoplanet's atmosphere. But understanding the impact of changes in that data is less tangible. As we look to 2040, what do the scientists say about the future? What might life be like two decades from now?



BIODIVERSITY LOSS

Despite what we knew about protecting biodiversity in 2006, the key threats of land clearance, habitat fragmentation and climate change haven't altered.

During the decade ending in 2019, the International Union for the Conservation of Nature (IUCN) declared 160 species extinct. These include the Australian natives the Christmas Island pipistrelle (*Pipistrellus murrayi*), a microbat, and the Bramble Cay melomys (*Melomys rubicola*), a small rodent that has since been declared the first mammal to become extinct due to climate change.

Some biodiversity experts have begun to predict an even less certain future for Earth's diverse plants and animals – a sudden, "cliff-edge" loss of biodiversity rather than a slow and steady demise.

A 2019 study published on Nature.com suggested that biodiversity losses could happen "much sooner this century than had been expected" and "that a high percentage of species in local ecosystems could be exposed to potentially dangerous climate conditions simultaneously".

Already battling chytrid fungus across the globe, frogs are likely casualties of climate change. Humpback whales are one species that's enjoyed increased numbers in recent times.

And it's not just species that will likely be affected, but entire ecosystems. The coral reefs of the Great Barrier Reef, having already experienced seven mass coral-bleaching events between 1998 and 2022, are at similar risk according to the study: "The risk of climate change causing sudden collapses of ocean ecosystems is projected to escalate further in the 2030s and 2040s."

Climate change may be particularly problematic for animals with highly localised habitat, such as the beautiful nursery frog, which is found only above 1100m elevation on one mountain – Wandu or Thornton Peak – in Queensland's Daintree Rainforest. Unlike "typical" frogs, nursery frogs lay their eggs on land under rocks or logs in moist soil, and skip the tadpole stage altogether.

"One of our key concerns with nursery frogs is whether their terrestrial breeding makes these frogs even more vulnerable to climate change," says Conrad Hoskin, an associate professor in terrestrial ecology at James Cook University Townsville. In coming years there's likely to be a reduction in the cloud moisture levels that traditionally give Wandu a beautiful nursery frog-friendly climate.

(FROG) FROGMANA / WIKIPEDIA. (WHALE) SHARE YOUR EXPERIENCES / GETTY IMAGES.

(DINOSAUR) NATURAL HISTORY MUSEUM, (FISH) KEN KIEFER 2 / GETTY IMAGES

"In our opinion, it has about a about a 50/50 chance of going extinct in the next 20 years," says Hoskin.

Can technology, which promises so much in other fields, help in the fight to arrest biodiversity loss? The growth of such things as environmental DNA analysis and acoustic sensors to constantly monitor species and collect data would seem positive.

Jacinta Plucinski is a software developer at conservation technology company Freaklabs. Plucinski predicts that the falling cost of conservation technology – and therefore its widespread use – will continue to improve the collection of data for imperilled species.

"The cost of technology goes down every year, so over time, sophisticated technologies like satellite imagery, bioacoustics, and camera traps will become more affordable and accessible," Plucinksi says.

But she cautions that the data that technology gathers is only as good as the systems and policies it informs.

"AI will play a big role in conservation technology in the next 20 years – but technology is just a tool for collecting data. Data needs to facilitate understanding and decision-making, and ideally be transformed into policy that can help promote conservation and biodiversity."

Far from the moist clouds of the Daintree, the future of our polar ice caps doesn't look much better than that of the beautiful nursery frog, according to Tim Flannery.

"The projections are that by the mid 2030s, we will be seeing ice-free summers in the Arctic," he says. "For Antarctica, the collapse is so catastrophic and unexpected, nobody has any idea really what's going on or what the future holds."

"AI will play a big role in conservation in – but technology is just a tool for collecting data. Data needs to facilitate understanding and decision-making."

The collection of data and its beneficial application to solving biodiversity issues has come on in leaps and bounds in the past 20 years, and will surely expand exponentially in the next 20. But what if we were able to access untapped data that has accumulated over – let's say – the past 20,000, 30,000 even 40,000 years?

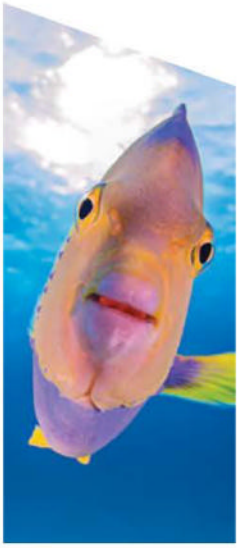
For ecologist Dr Jack Pascoe, a senior research fellow at the University of Melbourne's School of Ecosystem and Forest Sciences and leader of the Conservation Ecology Centre, that's what makes First Nations people around the globe so central to the ongoing fight for biodiversity.

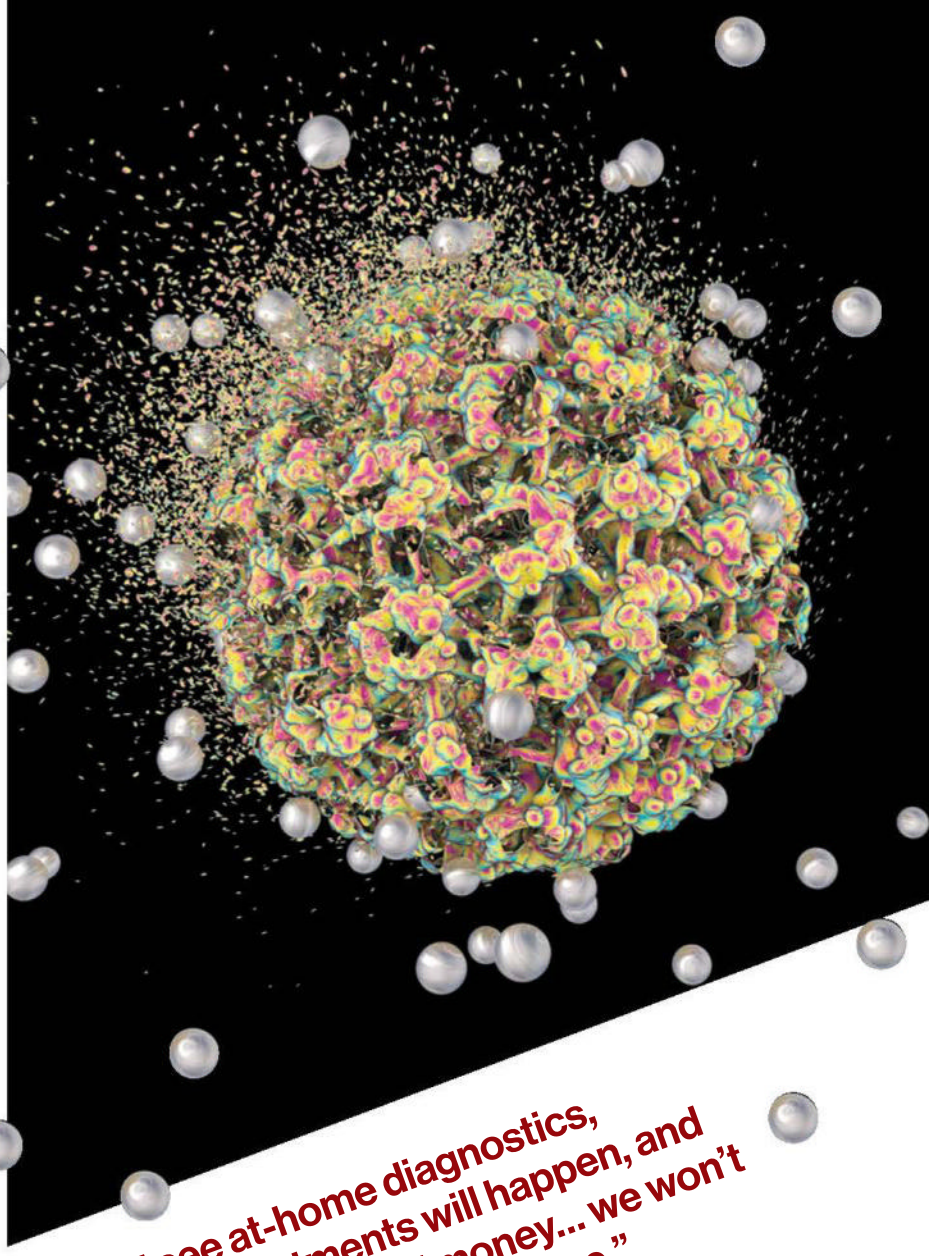
"More than ever before, the conservation movement is seeking input from indigenous peoples, not only for traditional ecological knowledge, which is so valuable to practical land custodianship, but also in an effort to understand the complex reciprocal relationship the mob had with Country that enabled such a light footprint."

Pascoe says indigenous peoples also play a critical role in the science of conservation.

"Science is based on knowledge derived from repeated observation. Tens of thousands of years of repeated observation builds quite a data set. This explains the complexity of traditional knowledge systems and also gives some insight into how Australia's First Peoples were able to adapt to such drastic changes in the climate and landscape."

In recent years *Cosmos* has covered (left–right from opposite top) deep geological time, eucalypt diversity and Australian dinosaur discoveries. In issue 89 we considered the case for fish intelligence.





BYE-BYE **CANCER?**

Cancer will likely still be a feature of life in 2040 says Will West, CEO of CellCentric, a UK-based cancer research company.

"We will never 'cure' cancer, but we can certainly prevent more cases, and keep people alive for longer, and healthier," he says.

For people diagnosed with cancer – a projected 1,958,310 people in 2023 in the US alone – this may be grim news. But as we predicted in 2006, cancer research, detection and treatment continues to be as multi-faceted as cancer tumour types themselves.

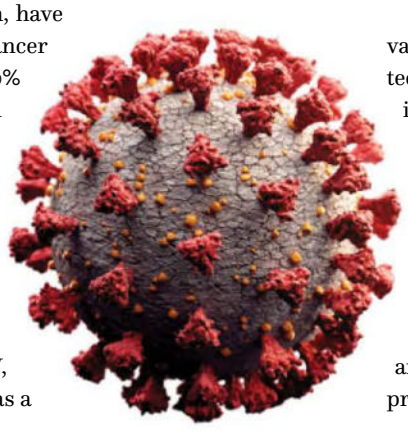
"An increasing number of cancers *are* cured," says Paul Grogan, senior strategic adviser for the Daffodil Centre. "Rates are around 40% higher than they were three decades ago, with a significant percentage of survivors living cancer-free. Five-year survival over the same period has improved for all cancers combined from around 65% to 70%."

Two of Australia's biggest cancer success stories in the last decade, according to Grogan, have been bowel and stomach cancer. Bowel cancer mortality rates having fallen by around 40% over the past 15–20 years, mainly through improved early detection.

One of the gold stars for cancer research is the development of vaccines for cancer-causing infections, including the human papillomavirus (HPV) vaccine, research for which commenced in the 1980s.

"The availability of a vaccine for HPV, which causes almost all cervical cancers, was a gamechanger," says Grogan. "It has enabled the introduction of a more effective screening test and a three-pillar strategy integrating immunisation, screening and improved treatment pathways to eliminate the disease as a public health issue. Australia is on track to be the first country in the world to achieve this, by 2035."

"We'll see at-home diagnostics, at-home treatments will happen, and that will save a lot of money... we won't need a stethoscope anymore."



According to Grogan, however, it's not just vaccines or improved detection and treatment technology that stand to further decrease cancer's impact by 2040.

"Some of the greatest gains will be in equitable application of interventions which we already know are effective."

The future for cancer in Australia depends largely on prevention, says Grogan, pointing out that "one in three cancer cases are preventable, yet Australia continues to invest only around 1.5% of its health budget in disease prevention."

TOP: KATERYNA KON / GETTY IMAGES. LEFT: RADOSLAV ZILINSKY / GETTY IMAGES.

MEDICAL **AI**

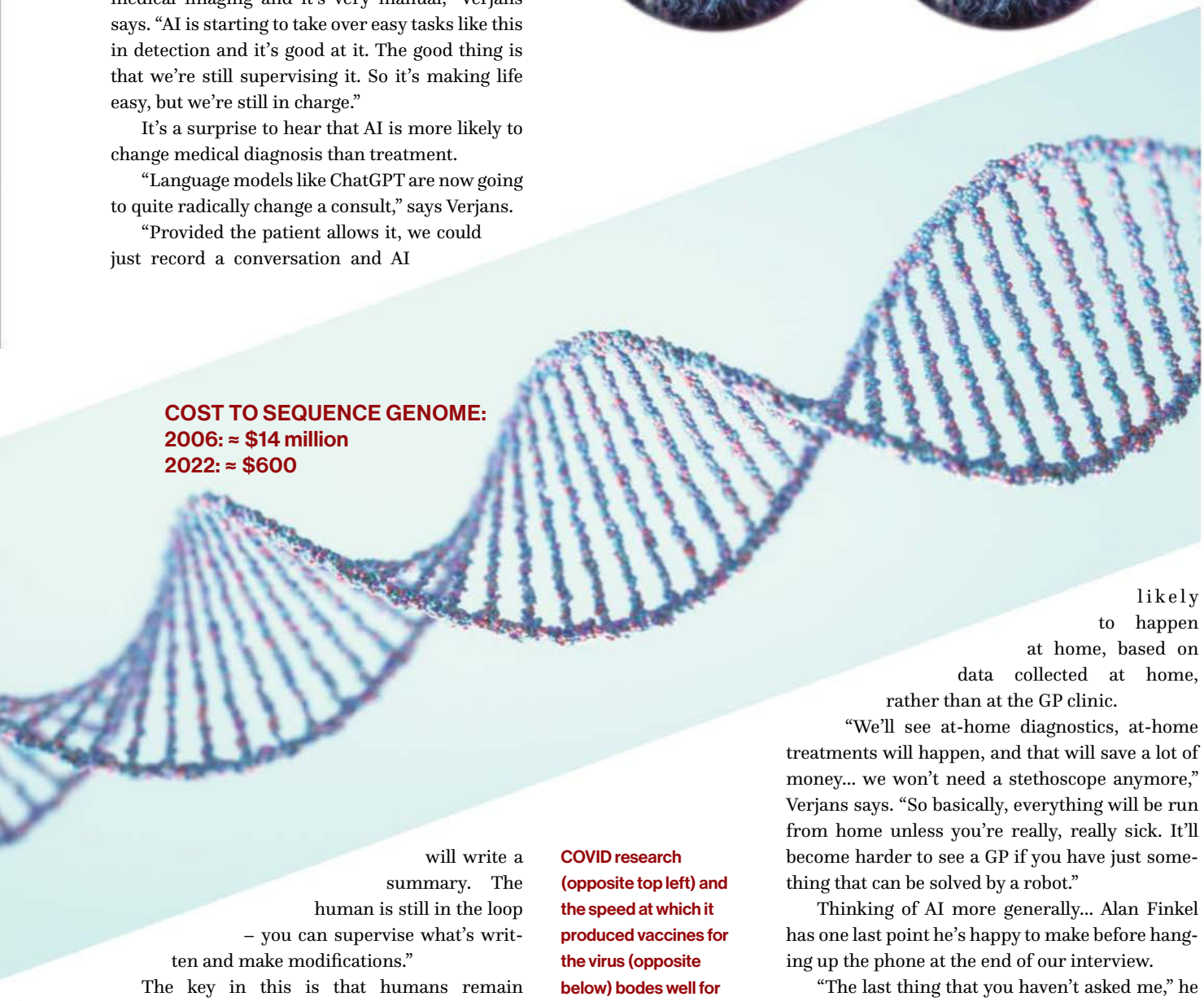
Cardiologist Johan Verjans, an associate professor at the University of Adelaide and deputy director at the Australian Institute for Machine Learning is seeing AI assistance in many areas of cardiology, but perhaps not in the ways that people might have imagined.

"We do a lot of measurements when looking at medical imaging and it's very manual," Verjans says. "AI is starting to take over easy tasks like this in detection and it's good at it. The good thing is that we're still supervising it. So it's making life easy, but we're still in charge."

It's a surprise to hear that AI is more likely to change medical diagnosis than treatment.

"Language models like ChatGPT are now going to quite radically change a consult," says Verjans.

"Provided the patient allows it, we could just record a conversation and AI will write a summary. The human is still in the loop – you can supervise what's written and make modifications."



COST TO SEQUENCE GENOME:
2006: ≈ $14 million
2022: ≈ $600

The key in this is that humans remain informed and alert, says Verjans. "AI, like humans, is pretty good. But it still makes errors. So if the computer is right 98% of the time, how can you actually be alert to something that is wrong 2% of the time? How do you find the 2%?"

Verjans predicts that AI will be diagnosing broken bones in the next 5–10 years. Clinical trials will also be done in a more affordable way by recruiting large numbers of study participants via smart technology. And diagnosis is more likely to happen at home, based on data collected at home, rather than at the GP clinic.

COVID research (opposite top left) and the speed at which it produced vaccines for the virus (opposite below) bodes well for medicine's future. Vaccines against cancer-causing infections – such as HPV (opposite top right) –are a focus of development. The reduced cost of genome sequencing has sped the development of personalised treatments.

"We'll see at-home diagnostics, at-home treatments will happen, and that will save a lot of money... we won't need a stethoscope anymore," Verjans says. "So basically, everything will be run from home unless you're really, really sick. It'll become harder to see a GP if you have just something that can be solved by a robot."

Thinking of AI more generally... Alan Finkel has one last point he's happy to make before hanging up the phone at the end of our interview.

"The last thing that you haven't asked me," he says, "is whether artificial intelligence will have taken over the planet by 2040. The answer is I don't know. At this moment in time no one – governments, entrepreneurs, technologists, scientists – really knows the extent of the threat and how to manage it. It does feel like a scary moment in time. But I'm confident that we'll work it out."

BRON WILLIS is based in central Victoria. Her story on human-centred software appeared in Issue 95.

FROM TOP: GANDEE VASAN; KTSDESIGN / GETTY IMAGES.


A chemist's guide to optimism

Not all science is equal in the sustainability stakes, but as **Ellen Phiddian** reports, a new generation of chemists are still focused on solving problems – but now they're going clean and green as well.

I am the sort of fool who bets against rain in the tropics. I decided not to pack a raincoat or an umbrella on this trip to Cairns; now, it's day one and I'm faced with crossing town on foot in a downpour.

Fortunately, there's an open supermarket right near my hotel, with a rack of foldable umbrellas next to the door. I buy one for $10. It keeps me and my laptop dry for the next four blocks.

It occurs to me as I reach my destination that rocking up to a sustainability conference with a brand-new, mostly plastic umbrella – the third such one I own – is perhaps a worse look than turning up soaking wet. I pull the tag off surreptitiously, and notice that there's a small tear in the umbrella canopy where it had been punched through. So it's also on its way to disposable.

Over the next three days, my umbrella becomes something of an albatross, dangling from my wrist. I'm in Cairns to cover the first Australian Conference on Green and Sustainable Chemistry and Engineering: several hundred people gathering to discuss how chemistry can make the world sustainable. The crowd is mostly research chemists, but there are also engineers, patent attorneys, industry reps – anyone who works with molecules is welcome.

The fact that it's happening at all is surprising to some. Chemistry is a filthy science. It's a discipline that evolved from alchemists in smoking laboratories, changing their greedy fascination with gold and immortality into a systematic fascination with money and health. And according to some of the attendees, it's now become something of the "monster under the bed" in environmentalism.

Chemistry's track record is thoroughly mixed. In the past century, chemists have turned air into ammonia, and then fertilisers and chemical weaponry. They've invented molecules that become life-saving medications, which large companies sell at high cost to make huge profit. They've spun carbon atoms into plastics that facilitate every aspect of modern life, and choke the oceans. And they haven't always been as enthusiastic as other scientists about sustainability.

"When Rachel Carson started the whole environmental movement with *Silent Spring*, I think the chemical community did a poor job embracing that process," Dr John Warner, one of the conference headliners, tells me.

I've met Warner with his long-time collaborator and the other conference headliner, Professor Paul Anastas, in a humid corridor during the "one half-hour" they both have free. But neither of them act like they're in a hurry.

They also keep quoting each other while we speak. They're childhood friends, from the same town in Massachusetts, who have now been working with each other for decades. And at the start of their careers, they watched chemists distance themselves from the environmental movement. According to Warner, the decades following the 1960s saw chemists double down on their craft, and ignore its effects. Anastas believes that by the early 1990s, "everybody but the chemist" was trying to solve environmental problems.

"The chemists only had one role in the early '90s, and that was to measure how bad the pollution was," he says. For these two, it seemed absurd. So many of the biggest environmental challenges – recycling, carbon dioxide, energy storage, monitoring – fall within the domain of chemistry.

"The people with the most power, the most influence, the most ability to actually change this equation, weren't involved," says Anastas.

But there were enough interested chemists to start a movement: green chemistry. Warner and

MAMSIZZ / ADOBE STOCK

Anastas spearheaded its growth in the US, publishing *Green Chemistry* in 1998. In it, they outlined 12 principles (right) for chemists to follow when doing their work. Instead of just focusing on the final product, made as cheaply as possible, green chemists begin by considering each of these principles.

It's hard work. But Warner, with over 300 patents to his name, reckons it hasn't slowed him down. In fact, done properly, he believes green chemistry saves money and time. No one throws resources into research and development, only to find their promising new reaction uses a solvent that's slightly too toxic when it hits the manufacturing wing. No one spends millions in litigation or redesigning when people and governments find their practices are polluting waterways.

"Had that first chemist understood green chemistry – not always, things are still going to slip through the cracks – but there is a much better chance that [...] they will avoid those profound mistakes that become very costly to industry," he says.

One of Warner's inventions is a way to dodge hair dyes, many of which are toxic to the waterways they end up in. Warner's treatment, derived from velvet beans and called Hairprint, uses melanin instead. As we age, the melanocytes in our scalps stop making melanin, the pigment that gives our hair its colour. Hairprint returns that melanin – and because it originally sat in our hair, it's incorporated back in the same way, resulting in the same colour one's hair originally was. For now, it only works with eumelanin, which yields black or brown hair – sorry, pheomelanin-stacked redheads and blondes.

UMBRELLA: COOLVECTORMAKER/ GETTY IMAGES. JOHN WARNER

"So many of the biggest environmental challenges – recycling, carbon dioxide, energy storage, monitoring – fall within the domain of chemistry."

Warner was the first person to try his hair treatment. Similarly, he dug up his own driveway to test a new asphalt binder. The non-toxic, environmentally friendly substance undoes the hardening oxidation reaction that asphalt undergoes while it's sitting in our roads – making it soft and easy to re-use. Now sold as Delta S, the binder lets road builders re-use much more of their old asphalt.

Neither of these products is perfect. Warner hasn't yet made something that addresses all 12 principles. "Right now, there are people dying of cancer," he says. "If I can get to market stopping this thing from being a carcinogen, and it's still not the most biodegradable, that's the way science works."

Dr John Warner

Anastas has spent more of his time with the US Environmental Protection Agency, but there are a few inventions that bear his stamp. One of his PhD students, Stafford Sheehan, has developed a process of particular note: it reacts CO_2 with hydrogen, forming a mixture of alcohols, water and a class of chemicals called alkanes.

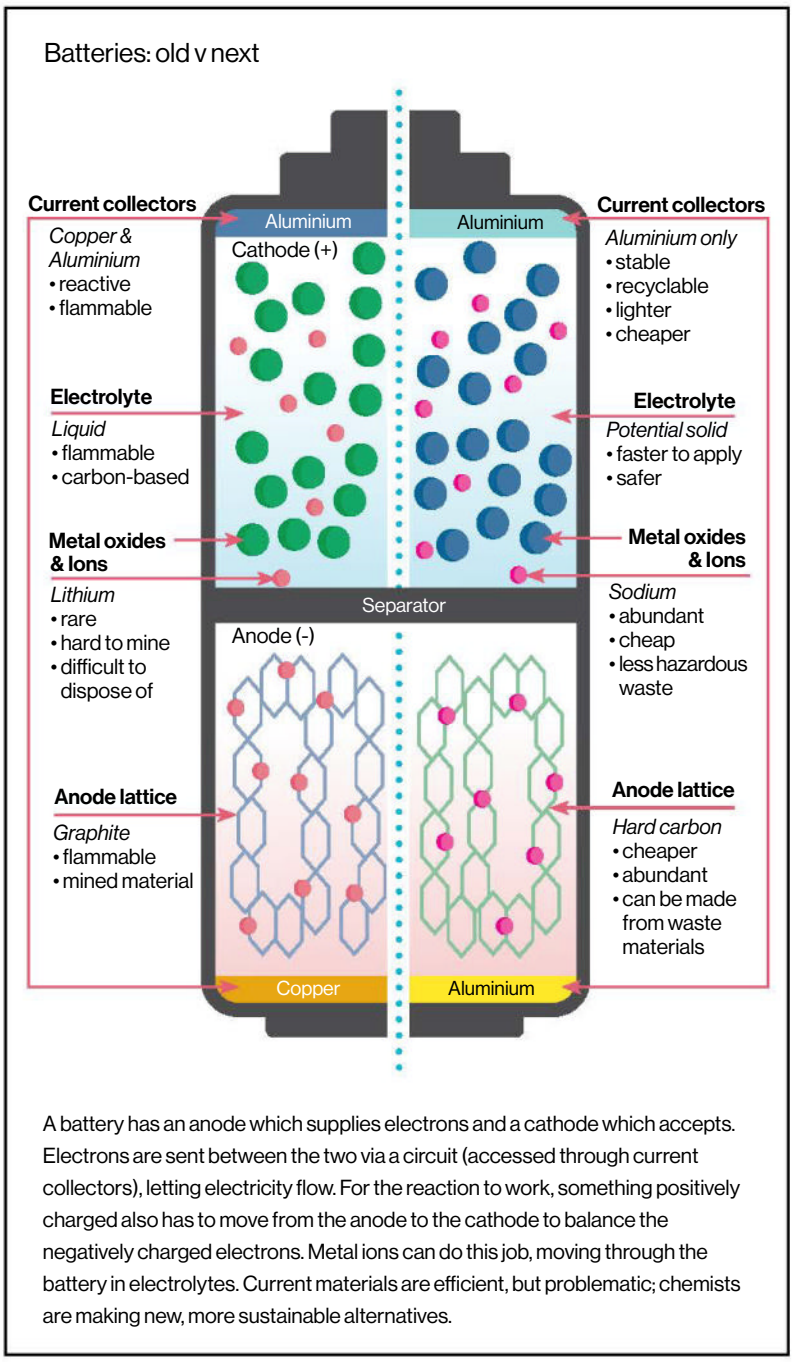
This has now spun out into a business called Air Company, which takes CO_2 captured from industrial plants and turns it into vodka, hand sanitiser and perfume. For now, the goods are small fry – but Air Company plans to make jet fuel. Given jet fuel pumps CO_2 straight back into the atmosphere once it's burned, this would be circular rather than carbon-negative – but it's certainly an improvement on our current, one-way fuel.

The challenge, now, is to get everyone else on this wavelength. Green chemistry has flourished in the past 25 years, but it's not yet the standard.

"It is a paradigm shift. But I'd like to believe that it's an evolution as opposed to a revolution," says Warner.

"Evolution's good. Revelation's better," says Anastas.

Both Anastas and Warner understand that they need to take other chemists with them. It's why, when Professor Colin Raston wrote to them in the late 1990s about starting the Australian green chemistry movement, they got back in touch promptly to lend their expertise. A quarter of a century later, they've given up their 4th of July celebrations to come to a rainy Cairns and speak at the conference Raston is co-chairing. Shut in from the rain, the venue is warm, dark and damp: perfect for fermenting ideas.



A battery has an anode which supplies electrons and a cathode which accepts. Electrons are sent between the two via a circuit (accessed through current collectors), letting electricity flow. For the reaction to work, something positively charged also has to move from the anode to the cathode to balance the negatively charged electrons. Metal ions can do this job, moving through the battery in electrolytes. Current materials are efficient, but problematic; chemists are making new, more sustainable alternatives.

ILLUSTRATION: GREG BARTON

A handful of inventions from two chemists – even really brilliant ones – won't stave off environmental destruction. But thousands of inventions, from people all over the world? That's got potential. This is why Warner thinks the most important thing now is to change chemistry education.

"If we change education, there's enough diversity of people that can go out there and start solving problems. And I don't have to prioritise, because we get them all," he says.

Doing the right thing

After I've finished speaking with Warner and Anastas, I realise my new umbrella is missing. I find it in one of the conference rooms: it had rolled under a chair I was sitting on a few hours earlier.

The person who made its handle didn't care about the person who made its canopy. They don't fit together – it's awkward and loose. The person who attached the price tag to it didn't care that they were puncturing the fabric. None of them cared about me, struggling to keep this bad umbrella stable in a storm that evening. And I didn't care about any of them, or I would have spent more than $10 in the first place, and kept a closer eye on it.

Professor Edward Buckingham, now director of engagement at Monash University's business school, is familiar with these chains of apathy. Buckingham has the air of a polymath - he quotes everyone from Machiavelli, to Marx, to Manuel (the young man he was speaking to when I approached him for an interview). He started his career as a materials scientist, and was running a manufacturing line in France when he started to change his mind about chemistry.

"We made the tubes and the stoppers that effervescent tablets come in, and we consumed about 18 tonnes of polymer every day: mostly polypropylene, but polyethylene and a little bit of polystyrene as well," he says.

"I was walking in the forest of Fontainebleau near my home, which is a forest just south of Paris. And I found one of my tubes lying in the leaves. That upset me, because I thought: that's where my product ends up. We don't recycle it."

He took it to his boss, who dismissed him – saying their company's pollution was insignificant compared to others, and the tubes made people's lives more convenient. It started Buckingham thinking about what a limited role he had, where his primary goal was efficiency.

"There's this trade-off between efficiency and effectiveness," says Buckingham. Efficiency, he says, quoting management author Peter Drucker's definition, is "doing things right" – while effectiveness is "doing the right thing".

"What happens further down the value chain to the product that I produce? What happens when it combines with other products and creates some unintended consequences? Efficiency doesn't deal with that."

Buckingham is now an ethnographer, but he still runs workshops on business design for budding scientists – having started in sciences, the field isn't foreign to him. He's at this conference to try and get pure chemists thinking about how industry sees their work, and hear the chemists' perspectives.

One of those chemists is Professor Maria Forsyth, from Deakin University, who works on one of the most ubiquitous and problematic pieces of chemistry on the planet.

Lithium, as the lightest metal, is undeniably the easiest way to make a powerful battery. It's hard to imagine electric vehicles or phones made with anything other than lithium-ion batteries. But in situations where weight isn't as crucial – like a home or grid-scale battery, or even an electric lawnmower – we don't need to use such a scarce resource. Abundant sodium, sitting just below lithium on the periodic table, shares many of its features for a much lower price.

"If you can have a manufacturing plant that can make lithium-ion batteries, you can swap in sodium-ion batteries," Forsyth says.

Forsyth is rushing to get things done right. In a 40-minute presentation to the conference, she packs in enough information to fill six undergraduate lectures on sodium-ion batteries. She goes even faster to get more words in when I interview her: I need more of the technical stuff explained in detail.

Sodium-ion and lithium-ion batteries share all the same parts, but the chemical makeup of those parts is different. This is why sodium-ion batteries are still, for now, only buyable for specialist applications: chemists haven't optimised them yet. Forsyth believes we're about five years out from full commercialisation – and that the batteries can be optimised in more than just price.

"We have an opportunity to make the devices that we make more sustainable, and more easily recyclable," she says.

Take the battery anode, which supplies electrons in one half of the battery. In lithium-ion batteries, the anode is typically made of graphite. Sodium doesn't play as nicely with graphite – the atoms are too big – but it does work with another form of carbon, called hard carbon, which can be made from junk: waste biomass. Forsyth and colleagues have been toying with anodes made from biochar, green waste and even unwanted textiles.

Then there's the current collectors, which connect the anodes and cathodes with the outer circuits. Lithium needs both copper and aluminium in its current collectors, but sodium can use just recyclable aluminium. Or electrolytes, which transfer positive ions within the battery. Forsyth and colleagues are designing solid-state electrolytes for sodium batteries, which will be safer and therefore much less energy- and time-intensive to manufacture.

Professor Maria Forsyth, Deakin University, Melbourne

Forsyth wants to see onshore battery manufacturing in Australia – but she says we should "think about what we're doing" first. Once an industry is established, it's much harder to change it to be sustainable.

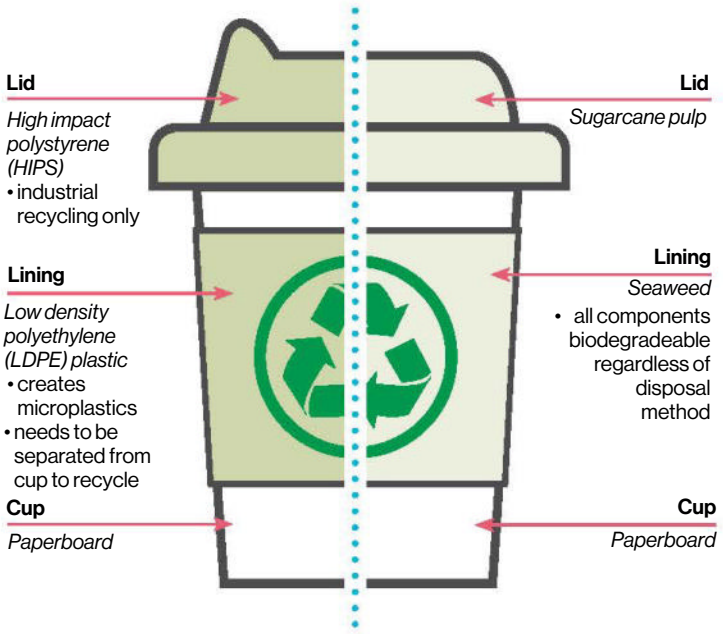
"One of the things that drives me at the moment is making sure that what we create now doesn't create a problem for the next generation," she says.

For Buckingham, paradigm shift is about perspective – and getting other people to see things from your line of sight.

"It's being able to reposition yourself in order to see a pathway through," he says. "That's what a paradigm shift is all about. Now, very often, you sail off down that street on your own, [and] no one else follows."

So it's crucial to get people from different backgrounds talking – and listening – to each other. If the chatter is anything to go by, the conference is a roaring success. People are swapping notes on their posters, figuring out where their research

"Recyclable" coffee cups: old v next



The plastic takeaway coffee cup might be heading for extinction, but newer disposable "recyclable" takeaway cups are still a work in progress.

ILLUSTRATION: GREG BARTON, FORSYTH: DEAKIN UNIVERSITY.

> "It's a philosophical shift: instead of making something as efficient as possible, make something as effective as possible."

fits together and asking keenly after each others' breakthroughs. Everyone keeps talking about the prevalence of PhD students and early-career researchers. These young chemists don't have the same confidence as their supervisors, but they're enthusiastic and clear: however their careers unfold, they know sustainability will dictate them.

At the conference dinner, an impromptu dance party starts. The senior academics lead it off, but – once enough of them have been coaxed to join – the younger crowd dances the longest.

Big-picture thinking

Prior to green chemistry, chemists were not monolithically careless about the environment. There were always concerned people who tried to minimise the effects of what they were doing. Professor Qin Li, an environmental engineer at Griffith University who is co-chairing the conference with Raston, knows this well: her late father was a chemistry professor who worked with paints.

"He was always telling me, 'Oh, this is, toxic, don't touch that.' When we had fruits and vegetables, I was always made aware of the pesticides on the surface," she says.

"Green chemistry is something in my veins."

Li's own research on particle movement started to get seriously environmental after her PhD, when she was looking at groundwater and aquifer recharge, and how her particle technology could improve clogging. She's carried this interest in water through her career – I catch her just after a breakfast workshop, where she and a dozen others have been discussing ways to repurpose wastewater.

"Where I think it is a paradigm shift is in asking the people who come up with the recipe to think in a holistic way, in a multi-dimensional sphere," she says. "They really need to look at: okay, it's not only just about removing dirt, but also about after removing the dirt. What happens to that surfactant? Because if it's going to end up in the environment, then it will also come back to us."

Professor Qin Li, Griffith University Brisbane

A future of solutions

The hotel tells me they have no use for my umbrella, so I stuff it into a coat pocket and take it on the flight home. On the plane, I draw up a plan for it based on things I've heard or seen at the conference.

The aluminium stretchers are simple to deal with – aluminium is almost as easy to recycle as it is to mine, and much less carbon-intensive. They'll be separated out and melted down, as will the steel in the springs. The fabric, probably polyester, can be burned into hard carbon, which could become the anode for a sodium-ion battery. This process still releases some CO_2, but that could be captured and added to Air Company's vodka. The hard plastic is trickier. I could use some sort of catalyst that breaks the polymers down (preferably not a heavy metal) – once broken, they could become carbon-based catalysts themselves.

I'm being flippant, designing this plan for 200 grams of plastic when I'm on a machine emitting several kilograms of CO_2 each second. But fixing the problem of jet fuel won't fix the problem of my junk umbrella, either. The path to a sustainable future is paved with several thousand small solutions.

They might be alchemists, but chemists have also always been crafters. They make molecules. For decades, these molecules have had one job: to do something as efficiently as possible. Now, more and more chemists are starting to think about everything else that happens to their molecules. Do they break down in the environment? Is there waste involved in making them? What else might they affect?

It's in the interests of both chemists and the companies they work for to start crafting molecules in this paradigm. Otherwise, they're betting against the rain: packing their hyper-efficient materials into a suitcase and thinking, foolishly, that the climate won't interfere. If more and more chemists are making things sustainably, the old methods will become, well, unsustainable.

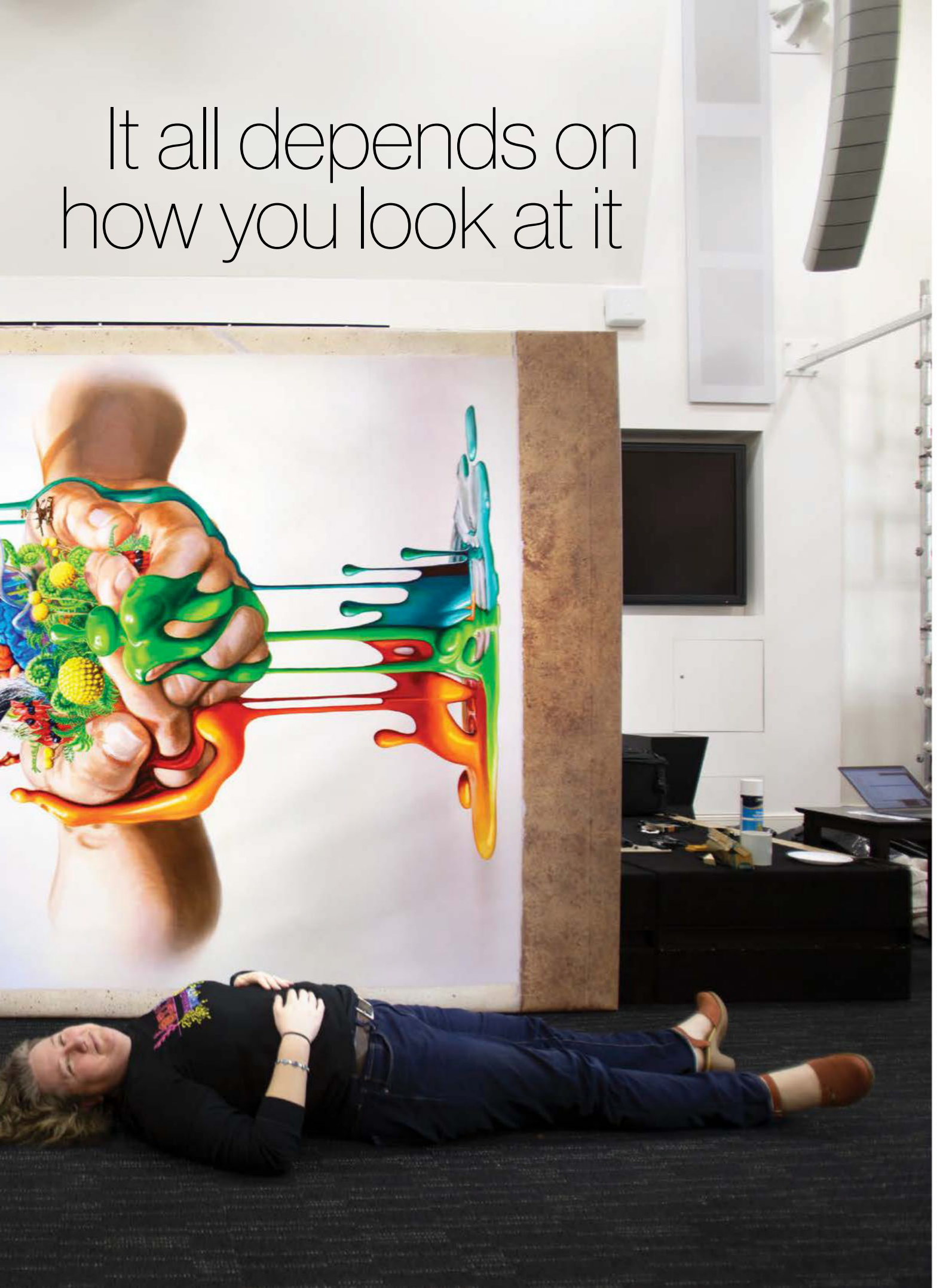
"We just laugh, or cry, when people say, 'Oh, chemistry is a mature field'," says Anastas.

"It is so nascent. It is at the beginning of its potential."

ELLEN PHIDDIAN is a journalist at *Cosmos*. Her story about sunscreen appeared in Issue 97.


COSMOS

It all depends on how you look at it



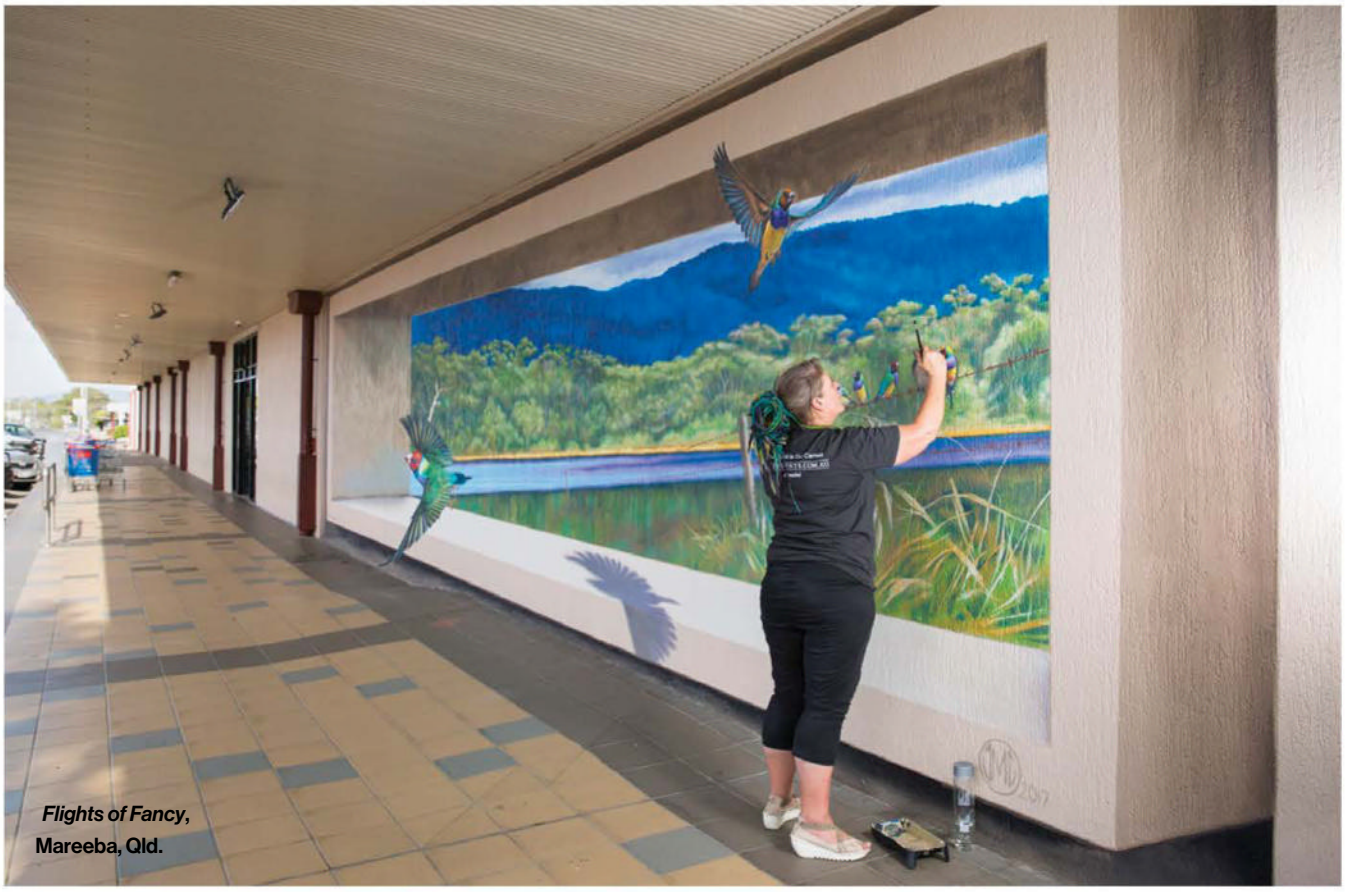
There’s no easy way to characterise perspective, no matter how far down a dictionary definition list you read. But the way we consider things will likely prove vital to our collective future.

Gail MacCallum & Ian Connellan

On a trip to Venezuela some years ago, we took a log-canoe tour of the Canaima Lagoon – arguably the most touristy part of a World Heritage Area that's best known for a modest cascade named, in Spanish, Salto Ángel, or Angel Falls – the tallest single-drop waterfall in the world.

The Rio Churún, into which Salto Ángel flows, runs into the Rio Carrao, which thunders into Laguna Canaima via five extraordinary waterfalls – saltos Hacha, Golondrina, Ucaima, Sapito and Sapo. The coolest part of the tour was walking behind the main flows of two or three of these falls. In spite of the warm air, we shivered in the swirling, cooling mist. We poked fingers and toes into the torrent to feel its force. It was like caving in daylight, risking oceanic-scale inundation with every slippery footstep.

Through the glassy wall of liquid, the churning nearby lagoon waters and the more distant La Gran Sabana landscape shimmered and distorted – a bit like viewing a modern street through a centuries-old stained-glass window in a church that's been swallowed by a city. It was the most unexpected perspective. Outside but inside. Sodden but not immersed. Underwater but breathing.



***Flights of Fancy*, Mareeba, Qld.**

MAREEBA, GULARGAMBONE, BARRABA: COURTESY ZEST EVENTS

Points of view

For artist Jenny McCracken, who painted this issue's cover, it's all about perspective. McCracken's seen it all, and painted it from every imaginable angle, in a three-decade career. She's been a Moran Portrait Prize finalist and – safety-tethered to a towering boom lift – she's painted silos in outback towns. She's won the world street painting festival (in 2015, in the Netherlands) and she's created the world's first 3D pedestrian crossing (in 2017, in Dunedin, New Zealand).

"I guess for me, it's about creating an illusion," says McCracken, who specialises in a type of perspective art called anamorphic distortion.

"Single point perspective takes you beneath the plane of the image, but [with] anamorphic distortion, it looks as if it's sitting above the plane, the surface plane.

"Single point perspective drags everything to one place – so it's still a distortion, but it's not as extreme, because it can only ever come into a single point and can't go any further. Anamorphic distortion theoretically goes forever – as far as the eye can see, or the paintbrush can reach."

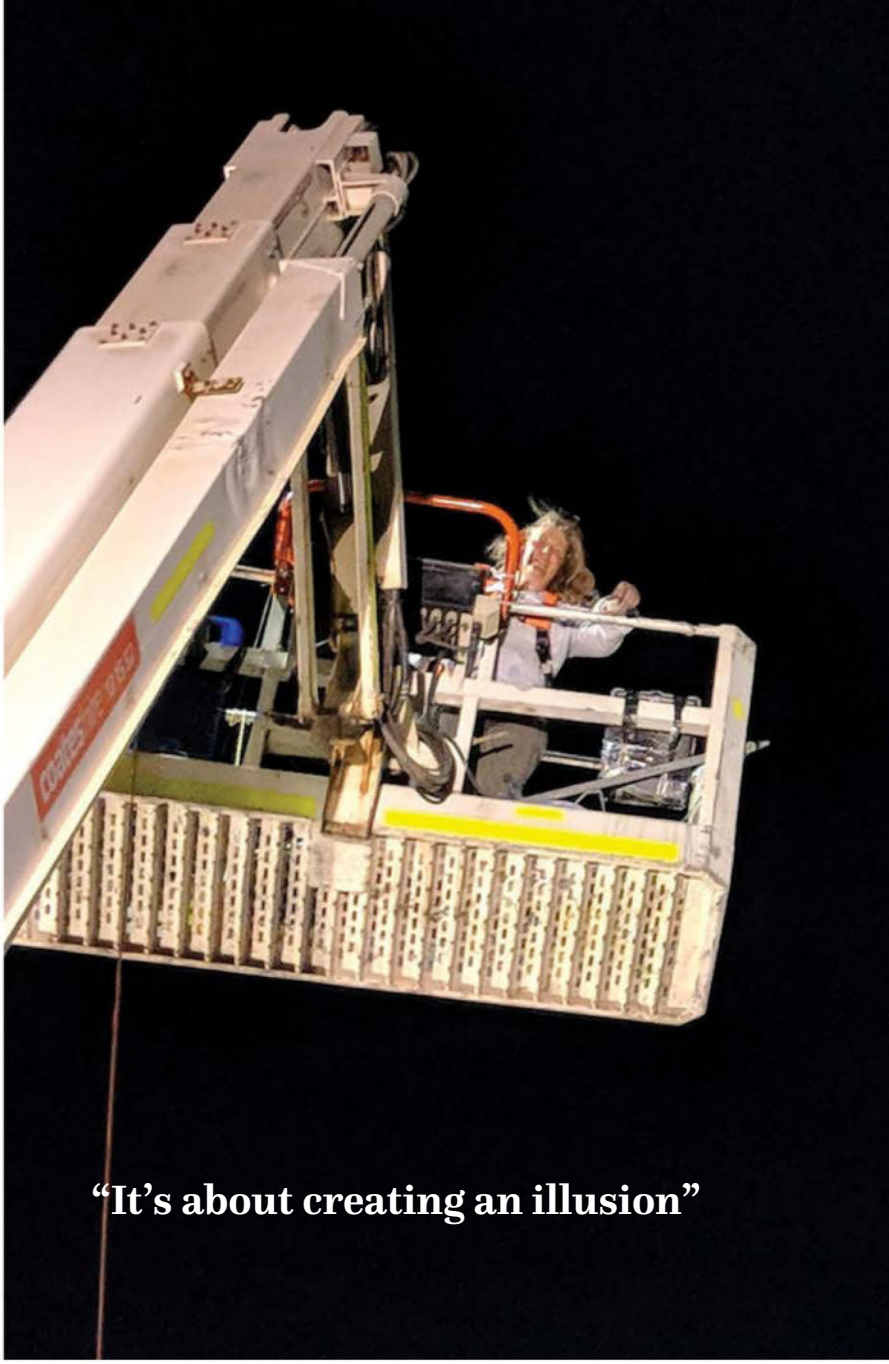
McCracken started out as a busking street artist, an endeavour that gave her access to "an unlimited canvas". She says that creating the illusion of an alternate reality in the street appealed to people, and was a better earner: "You knock people's socks off, they throw you more coins."

She says she's motivated both by the "pure mathematical perspective of creating an alternate, multi-dimensional image" and by "challenging people with stuff like environmental messages, which require a new perspective".

There's a funny thing about the background perspectives other artists bring to their work, McCracken says; it's often not what it seems.

"A friend of mine is probably the pre-eminent Dutch 3D artist," she says. "He has a condition well known and well described where he has no depth perception [stereo-blindness]. So he sees the world as a two-dimensional representation. And it's made him an exceptional 3D artist.

"Other perspective artists are reducing a three-dimensional world to a two-dimensional surface in order to create that illusion. He sees it like that all the time."



"It's about creating an illusion"

No detail too small, no tower too tall: Jenny McCracken's knack for perspective art has made her internationally renowned. In 2018, she transformed a water tower (above) in Gulargambone, NSW, into *Lucky Dip*. To create this issue's cover (left), she sketched a projection of the work, which she'd first rendered electronically, onto the canvas.

Beyond the walls, Barraba, NSW.

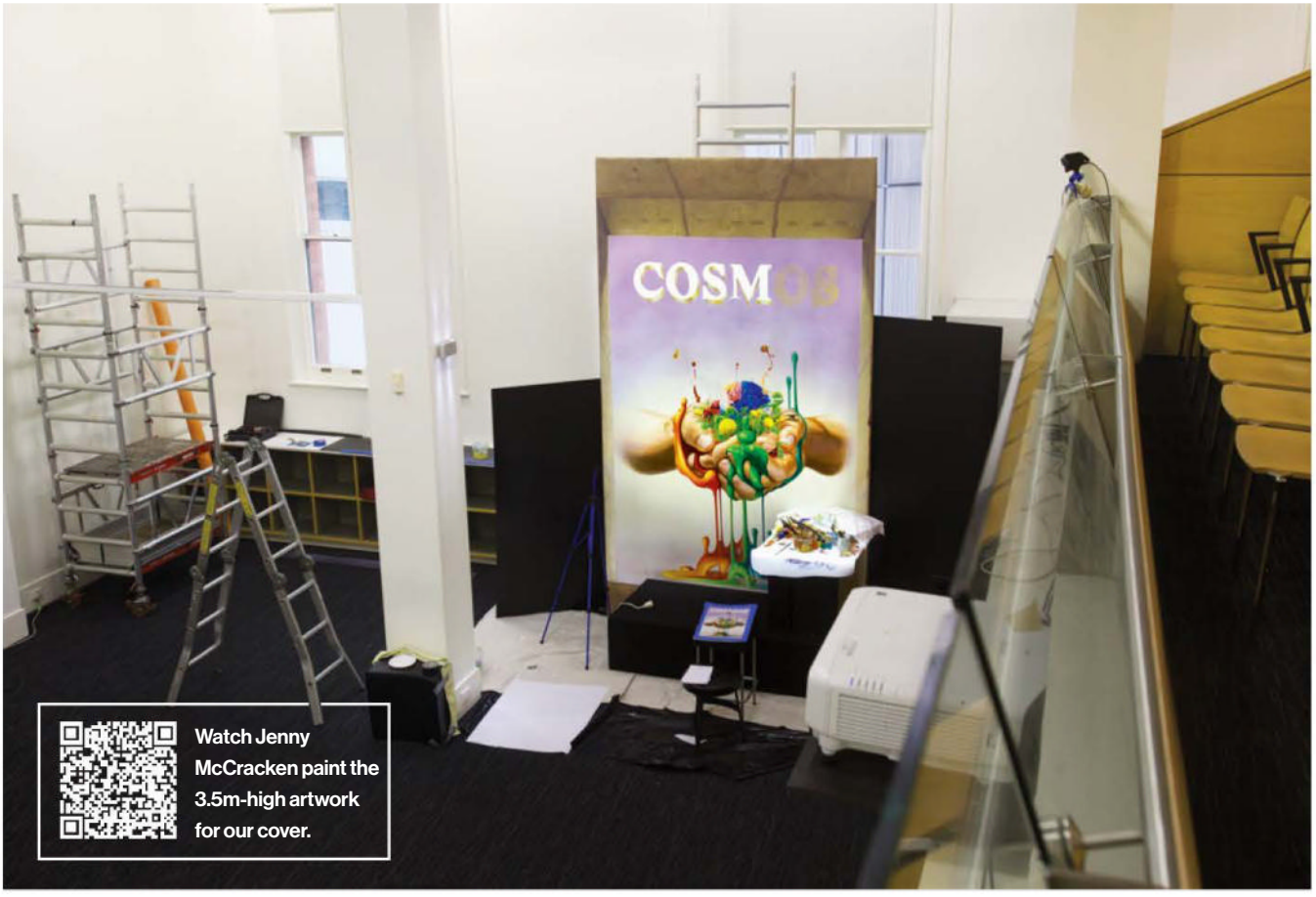
Best of times?

Charles Dickens opened his novel *A Tale of Two Cities* memorably: "It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair…"

The novel was published in 31 weekly instalments in 1859, the same year as *On the Origins of Species*. It was an era characterised by opposing perceptions – both good and bad, wise and foolish – which seem to be a permanent fixture of humans' curious reign as Earth's pre-eminent organism.

Looking through a waterfall from within, it's possible to get a sense of what's on the other side, but the edges of things aren't clear. The only way to find out is to step through the mist.

In a way, that's what science offers: gazing into a hazy future, designing experiments and questions that will bring the next step into focus. Scientists live in the same present as us, but every day they work towards our future, based on curiosity, hope and effort. It's a perspective shift we can all share.



Watch Jenny McCracken paint the 3.5m-high artwork for our cover.


COSMOS




Possum magic

The ancient relationship between mountain pygmy possum and the bogong moth reveals the complexity of global climate change – and the lengths we may have to go to save some species from extinction. **Kate Evans** reports on the risks for – and resilience of – this alpine adventurer.




(ALL MOTHS): DE AGOSTINI, SEPIA TIMES / GETTY IMAGES

ABOVE: ZOOS VICTORIA

Linda Broome pulls herself up a near-vertical slab of granite, leaps nimbly over a snow-lined fissure, and dives head-first into a crack in the rocks. At 67, she knows Blue Cow Mountain like the back of her gloved hands. Every November for the past three decades, she has led volunteers up this 1,901 metre peak, and a handful of other high-altitude boulder fields in the Snowy Mountains. The team visits to monitor the population of critically endangered *Burramys parvus*.

It's springtime in the high country. Drifts left by a late snowstorm are melting, and frogs croak enthusiastically in the fens. The nocturnal possums have hibernated under the snow all winter, dropping their body temperature to just above freezing for up to seven months. Then, a few weeks ago, they woke up. Broome, a threatened-species officer at the New South Wales state environment department, retrieves a rectangular aluminium trap from the crack and backs out. She carefully reaches inside, past a lining of cushion-stuffing, and retrieves a whiskery, mouse-like creature with black eyes and brown-and-gold fur.

She holds it by the base of its long, scaly tail, which curls around her finger. "It's alright, darling," she coos. "You're so sweet." Broome and volunteer Carlie Armstrong work together to insert a minuscule microchip into the folds of skin at the possum's neck, clip a snowflake-sized disc of skin from its ear for genetic analysis, and check for parasites.

They place the creature in a cloth bag and weigh it: 34 grams. This one is female, with a handful of jellybean-like joeys in her pouch, and seems unconcerned as she perches on Broome's finger and sips water from a bottle lid. While Armstrong uses the metal trap pin to nudge the possum's droppings into a vial, Broome releases the animal. She scurries over the neon lichen and disappears into a crevice.

The little marsupial's dual mission for the coming summer is to raise her young while doubling her body weight, so she's fat enough to hibernate again. Fortunately, breakfast has arrived on her doorstep.

Every spring, vast numbers of bogong moths (*Agrotis infusa*) migrate as far as 1,000 kilometres from the western plains of NSW and Queensland to the Australian Alps, crawling into caves and among the rocks to avoid the heat – a summertime form of hibernation called aestivation. The

alpine possums eat other invertebrates, as well as fruits, seeds, and nectar, but the fatty bogong moths are their favourite food; at the highest elevations, the migrating moths make up as much as 50% of their diet. "It's a massive movement of protein into the mountains," says Broome – one that feeds not just possums, but ravens, lizards, and other small mammals.

In the past few years, though, south-eastern Australia has ricocheted from drought, to fire, to flood, threatening to unravel the ancient, intertwined relationship between the moths and all the animals that depend on them – including the few thousand mountain pygmy possums that are left in the wild.

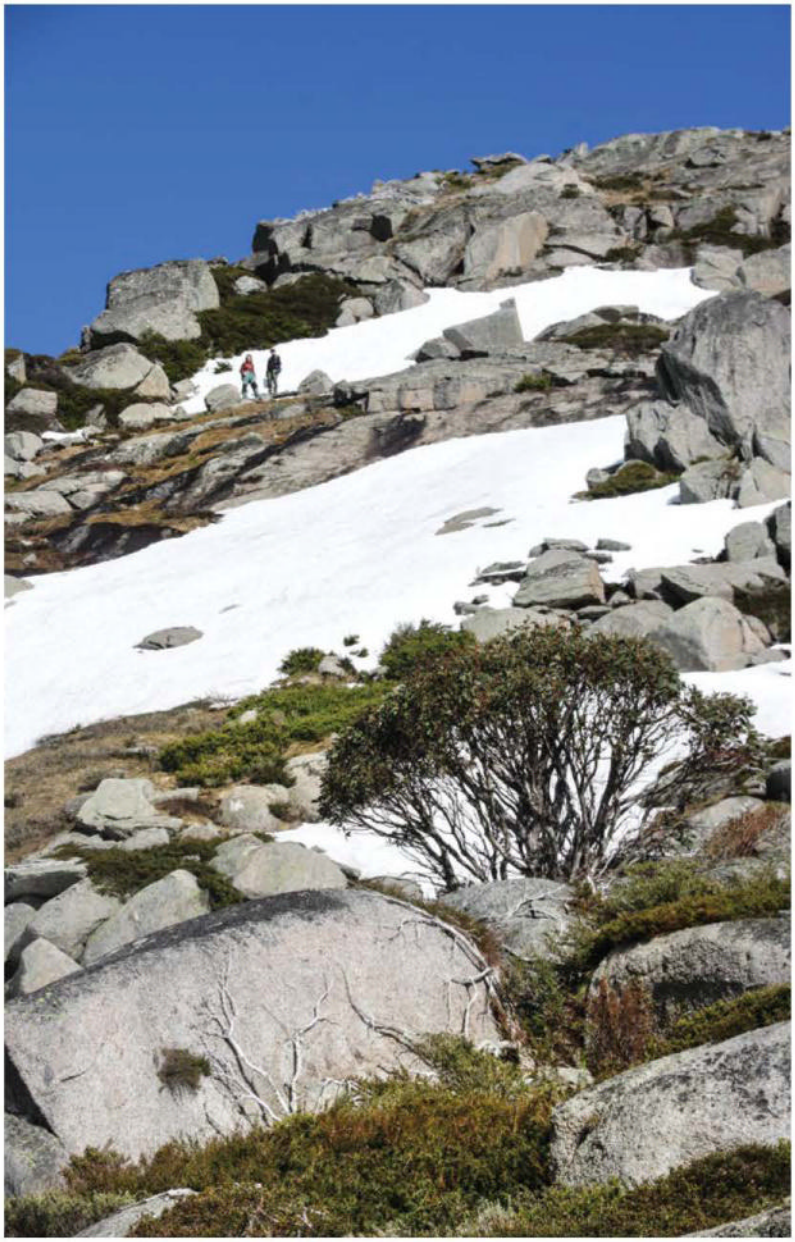
From 2017 to 2020, prolonged droughts in Queensland and western NSW caused moth numbers to drop from more than 4 billion to perhaps 20 million. As a result, baby possums starved in their mothers' pouches.

The dance between moth and possum demonstrates the complexity of global climate change, and how extreme weather in one place can alter environments thousands of kilometres away from it. Together, these creatures have become symbols of what Australia stands to lose in this warming century: unique species, ecological relationships, and even entire ecosystems, alongside human homes, livelihoods, and lives.

Living fossil

Until the 1960s, scientists considered the mountain pygmy possum nothing more than an interesting fossil. In 1894, Scottish doctor and palaeontologist Robert Broom had found minute-age teeth and jawbones in a limestone deposit near the Wombeyan Caves, between Canberra and Sydney.

The jaw featured an unusual tooth, "unlike that of any known marsupial," Broom wrote – a large premolar with six deep grooves that gave it a serrated edge. He denoted it Burramys. A few more fossil remains turned up over the following half-century, but it wasn't until August 1966 that people staying at a ski lodge in Mount Hotham, Victoria noticed some strange furry creatures stealing bacon from the stove. Australian naturalist Norman Wakefield took a look at a captured one and recognised its distinctive ridged tooth immediately. "Burramys had come to life," Ride wrote of the event. "The dream dreamed by every palaeontologist had come true. The dry bones of the fossil had come together and were covered with sinews, flesh and skin."



Because most other species of possum live in trees, ecologists assumed that the possums had hitchhiked to the lodge in a load of firewood. But by the early 1970s, they had been captured in the wild at various alpine locations in Victoria and NSW – even, in 1972, among the boulders near the treeless summit of 2,228m Mount Kosciuszko.

In the early '80s, as developers were building a new ski resort at Blue Cow Mountain, a national parks contractor discovered a population of pygmy possums precisely where the runs were being laid out. The state government set out to find someone to assess the resort's impact on the animals.

At the time, Linda Broome was living in Logan, Utah, in the USA. Having just spent four years tracking deer mice across the rolling sagebrush country of Wyoming, she was one of few

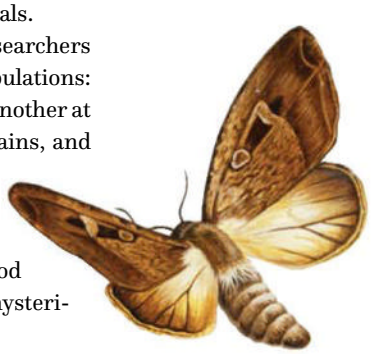
Researcher Linda Broome (opposite, at left) and volunteer Margaret Carr set traps on Blue Cow Mountain for pygmy possums, or Burramys (right), which Broome's been monitoring for three decades. Although Burramys is now specially adapted to alpine life, its fossil record – including jawbones (left) found at Riversleigh, in Queensland – indicate it once dwelt at lower altitudes. In the high country, the species relies hugely on bogong moths (above) for nutrition.

Australians who had worked with small mammals in the snow. She got the job, and came home.

For the next few years, she trapped the possums and fitted them with wedding-ring-sized radio transmitter collars and tracked their habits and movements, mostly at night.

And as winter blizzards raged, she clambered over the mountain in snowshoes with her radio receiver, finding the possums unexpectedly still. That was how she discovered that they hibernate – a rare behaviour for Australian mammals.

Over the decades, she and other researchers identified three genetically distinct populations: one in Kosciuszko National Park (KNP), another at Mount Hotham and the Bogong High Plains, and another at Mount Buller, also in Victoria. The animals' total numbers fluctuated between around 2,000 and 3,000 adults, depending on climate, food availability, and predators – and on the mysterious peregrinations of the bogong moths.



Winged feast

In September 2000, a strange cloud appeared on satellite maps, approaching Sydney. Weather forecasters worried that rain would disrupt the Olympic Games closing ceremony. But the "cloud" turned out to be a huge swarm of bogong moths. Attracted by the stadium lights, they tumbled dizzily above the spectators, and threw themselves against the soloist as she sang the Olympic hymn.

It was not the first time that bogong moths had been part of human celebrations. For the Aboriginal peoples of the high country, bogongs have been an important seasonal marker for thousands of years, says Jakelin Troy, a linguist and the director of Aboriginal and Torres Strait Islander Research at the University of Sydney. Troy's people are the Ngarigu, and the Snowy Mountains are her Country.

"Bogongs are just such a core part of our story," Troy says. "They blend in so beautifully with Country. They look like the granite, they look like fallen timber – and they have been this important source of food for my people." They're also delicious, she says. "Get all the mothy stuff off and they're like peanut butter."

The moths feature in stories and songs across south-eastern Australia. At Uriarra Station, a farm on the outskirts of Canberra, Paul Girrawah House of the Ngambri people introduces me to a sacred site. The Uriarra moth stone is a flat expanse of granite the size of a basketball court, overlooking undulating paddocks where sheep graze beneath forested hills. "Uriarra means 'running to the feast,'" House explains. "As soon as the bogong arrived, it was the sign. The message went out, and people came."

His ancestors collected the moths from nearby mountaintop caves and carried them here in dilly-bags woven from stringybark and reeds, to feed guests. The rock, House says, "is a feasting table", and everyone, friend or enemy, was invited and welcomed. Here and in the Snowy Mountains,

bogong moths fuelled summer festivals where marriages were arranged, ceremonies performed, trade conducted and disputes resolved.

By the mid-20th century, colonisation and land dispossession had largely ended these traditions. But the moths remain enormously significant, House says. Today, he has brought his son, Reuben, to see the stone for the first time, and to sing some of the old songs.

"To come back here, there's a feeling of empowerment," Reuben tells me. The 26 year old has the image of his Ngambri great-great-great grandfather, Henry 'Black Harry' Williams, tattooed on his shin. Above Reuben's knee, there's another tattoo: a bogong moth, flapping across his thigh. It's a symbol of his heritage, and of resilience, he says. Persistence in the face of change. The bogong moth "makes me feel strong", he says, "and more proud to identify as a Ngambri man, from here".

Migration mystery

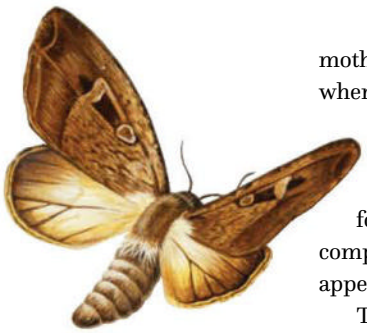
The bogong moth's annual migration is one of the world's natural wonders. Only the epic journey of the monarch butterfly across North America compares, says entomologist Eric Warrant, an Australian based at Lund University in Sweden.

While the monarch takes four generations to complete its migration, the bogong moth does it in one, starting at various sites on the western plains of NSW and Queensland, and returning home after their summer mountain sojourns.

"They've never made this journey before, and they have never had anybody to tell them how to get there, and their parents have been dead for three months. This is a terribly difficult thing to do," says Warrant.

In 2012, Warrant and his students began a series of experiments to investigate how the moths knew where to go, and how far to fly, and when to stop. Being nocturnal, they couldn't use the sun, and the moon's phases made lunar navigation unreliable. The tests showed the moths relied in part on their magnetic sense for navigation, but – like hikers training a compass needle onto a distant tree – they also appeared to use visual cues.

Bogong moths brought people together, fuelling summer festivals where marriages were arranged, ceremonies performed, trade conducted and disputes resolved.



The question was: which cues? Warrant thought that "the Milky Way is an enormously strong visual stimulus." To a moth, it probably looks like "a lovely stripe of light", brightest in the south, and fading as it arcs into the north.

At his holiday home near Adaminaby, near the northern end of the Snowy Mountains, Warrant put the idea to the test. He built a new lab from scratch in 2017. No magnetic materials were allowed; the roof was made of corrugated aluminium instead of steel, which contains iron. Inside was an arena where the moths could fly in a kind of magnetic vacuum, so the scientists could study the insects' visual sense in isolation.

Using a computer program devised for planetariums, Warrant's team projected the seasonally and geographically correct night sky above bogong moths they'd captured outside during their autumn migration away from the mountains. Inside the arena, with only the projected sky for guidance, the moths knew exactly where to go.

When the researchers rotated the sky image by 180 degrees, the whole population of bogongs

MERRILLIE REDDEN / SHUTTERSTOCK

turned and flew in the wrong direction. And when they randomised the stars' positions, the moths were completely disoriented.

"It is totally mind blowing," says Warrant. The moths have somehow inherited these star-maps and magnetic signposts from their parents, so they're born not only knowing which way to fly, but they can also correct their course on the wing.

And yet, these extraordinary creatures are suffering. Their numbers decreased after European settlement in the 1800s, then remained stable before declining gradually from about 1980. Researchers aren't sure why, but speculate about changes in climate, as well as land use in the moths' breeding grounds, such as clearing, increased grazing pressure, or pesticide use.

Until recently, however, they still numbered in the billions. In a typical year, the caves at the moths' first stopping-point – Mount Gingera, a 1,857m peak in the Australian Capital Territory's Brindabella Range – are "completely carpeted in moths," says Warrant. Each individual overlaps its wings with those of the moth next to it, a behaviour known as tiling.

But in 2017, the rain stopped falling. In the moths' winter breeding grounds on the plains, few plants grew, starving kangaroos and moth caterpillars alike. The following summer sweltered, and when Warrant went up to the caves on Mount Gingera, he found them bare. "From millions upon millions of moths, to nothing! That for me was shocking in the extreme."

Large populations can weather one severe year. But for the next three years, rainfall in the state was the lowest on record. Meteorologists estimated that temperatures on the plains were higher than at any point in the previous 2 million years. By the time the drought broke in 2020, Warrant and other bogong moth researchers calculated that the population had plummeted by 99.5%.

In 2021, the bogong moths joined the mountain pygmy possums on the International Union for Conservation of Nature's Red List of Threatened Species. That summer, despite two years of good rainfall, surveys of known aestivation sites in Australia's northern Alps, including Mount Gingera, the Main Range, and Blue Cow Mountain, found few to no moths.

There was a time when Warrant would have laughed at anyone predicting the bogong moth's extinction. Like 19th century Americans marvelling at the super-abundant passenger pigeon, he had thought the moths were invincible. Now, he says, it's clear that "this apparently incredibly resilient insect is very vulnerable to bad conditions".

Packed with protein, bogong moths (opposite top) once flew in such abundance that they were central to feasting and ceremonies of high country Indigenous peoples. Many gathered each year at the Uriarra moth stone (opposite bottom) on Ngambri Country when the moths were migrating; modern-day Ngambri men Paul Girrawah House, right, and his son Reuben still revere the site. The moths navigate by star-maps – the Milky Way (above) is a powerful cue – and magnetic signposts on the flight from their winter homes in western NSW and Queensland to the Snowy Mountains.

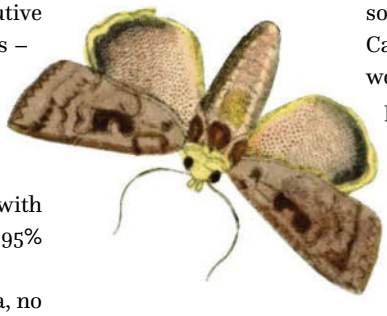
Possum 'uber eats'

It's 6:30 am, and Linda Broome is checking her moth traps at Charlotte Pass, a few kilometres south-west of Blue Cow Mountain. A bowl-like valley cups a clutch of ski lodges, its steep sides lined with gnarled snowgums and striped with chairlifts and pomas. Every year, Broome monitors the population of pygmy possums that lives among the boulder fields beside the road, and she has long kept an eye on their primary food source.

She lifts a funnel from the mouth of a white bucket perched on top of a rock, and removes torn pieces of newspaper. The moths – attracted by a light placed atop the bucket overnight – whirl manically underneath, the scales rising from their wings like dust motes in the light. "We've only got a few hundred here,"

Broome says. It's a partial recovery from the last few dire years, but nothing like the thousands she typically captured before the drought. Broome tips out the bucket and the moths scurry for the nearest crack. She shoos them deeper, out of the reach of bird predators such as ravens.

Ecosystems are complicated, and it can be hard to untangle cause and effect. But consecutive years of low moth numbers do harm possums – especially those at the highest elevations, where there's little alternative food. In Victoria, when bogong moth populations plummeted in the summer of 2017–18, researchers found possum after possum with their pouches full of dead babies. In one area, 95% of litters died.



"There were no signs of injury, no bacteria, no illness, no viruses," says Marissa Parrott, a reproductive biologist from Zoos Victoria. "They simply starved to death." The government team managing pygmy-possum recovery, including Broome, Parrott, and others, concluded this was a conservation emergency that required direct intervention. Zoos Victoria got to work on a long-term, possum-specific supplementary food program and came up with a recipe that mimicked the nutritional qualities of bogong moths, plus the other elements of the animals' natural diet. It included macadamia nuts, coconut oil, mealworms, egg white, and vitamins. A commercial company made the gourmet mixture up as a dry powder, and then the researchers baked it into bogong "bikkies". Trials with captive possums confirmed that the animals would eat the bikkies only if they couldn't get their bogong moths or other natural foods.

In November 2019, Parrott's team successfully tested their concoction in the wild among the struggling possums in the Victorian boulder fields, using a variety of different home-made feeders. But it wasn't until January 2020 that the bikkies really proved their worth. That month, Parrott got a call she would never forget. It was Linda Broome, and she didn't even say hello. "It's gone," Broome said. "There's nothing left." Bushfires sweeping across vast areas of Australia's south-east had hit northern KNP, near Cabramurra. The area's tinder-dry boulder fields were home to a thriving population of mountain pygmy possums that Broome and her team had discovered in 2010.

Broome knew the possums had likely survived, deep in the damp crevices. But when she visited days after the conflagration, she found the still-smoking hillsides devoid of vegetation and insects for the animals to eat, and no water for them to drink. "Please tell me your food and your feeder worked?" Broome asked Parrott. It was one of the proudest moments of Parrott's life that she could say yes – that the prototypes had been successful, and that they were ready to deploy.

Ecosystems are complicated... but consecutive years of low moth numbers harm possums – especially those at the highest elevations where there's little alternative food.

The Zoos Victoria team sent bags of bogong bikkie mix and prototypes of the feeders to Broome, and the volunteers got making and baking. Every week for the next two summers, National Parks and Wildlife Service discovery rangers, aided with baking by local school children, delivered fresh bikkies to 60 feeders stationed across the burned boulder fields.

By the end of 2022, the animals were thriving without support. Vegetation was returning only slowly, but other prey like bugs and beetles were already crawling around the boulders. The expensive, labour-intensive experiment had worked – proving that in extreme situations, audacious interventions can stave off disaster for endangered species.

"The outlook for the alpine zone as we know it is pretty bleak," says ecologist Lesley Hughes, an emeritus professor at Sydney's Macquarie University, IPCC report author and director of the Climate Council of Australia. Even before it's gone completely, dwindling snow cover will disturb the possums' winter rest. A thicker layer of snow

UNSW palaeontologist Mike Archer (left, with a rescued ringtail possum) and his colleagues have revealed much of life in Australia 25–12 mya through their work at the World Heritage listed Riversleigh fossil site in northern Queensland.

provides more insulation; without it, the animals' nests get colder, which could wake them from hibernation before moths arrive or seeds are available, Broome says. Snow is also a barrier to predators, and warmer winters allow feral cats and foxes to range more freely and hunt possums more easily.

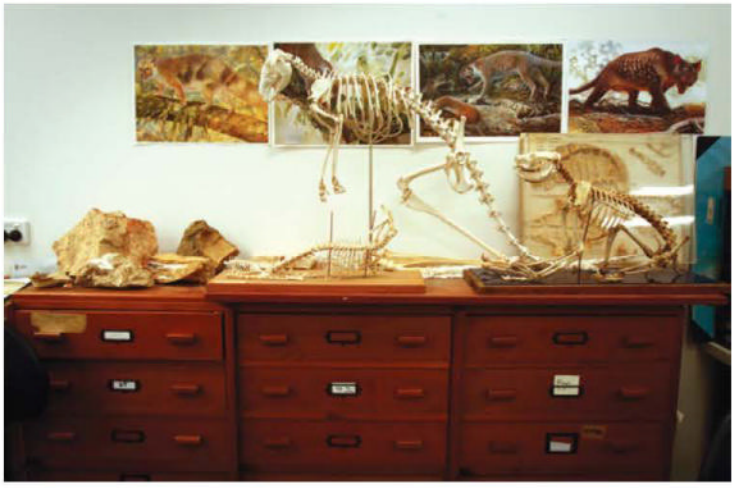
A lowland future?

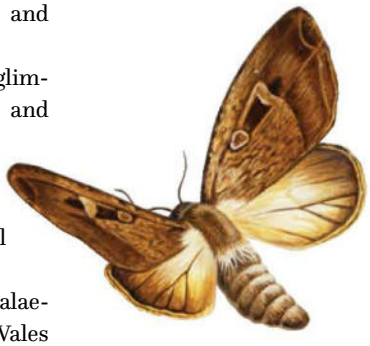
The mountain pygmy possum is often ranked among the Australian species most vulnerable to climate change: global efforts could still restrain rising temperatures, but the possums' high-altitude home has already begun its transformation. Even if conservationists continue to intervene with supplementary food when necessary – without snow, without moths, ravaged by fire and cats... Is its extinction inevitable?

The pygmy possums' deep past offers a glimmer of hope. Palaeontology reveals animals and ecologies in the fourth dimension – time. And some scientists believe that insights from the fossil record can offer surprising, if drastic, solutions to the environmental problems we face today.

I meet Professor Michael Archer at his palaeontology lab at the University of New South Wales in Sydney. Mounted mammal skeletons line the walls, and the benches are piled with academic tomes, jars of paintbrushes, bottles of acetone, fossilised skulls, and partially-prepared snake vertebra. Today, there is also a live ringtail possum in a box; Archer rescued it from the university cafeteria this morning when he stopped by to grab his coffee.

Since 1976 Archer has led excavations of the extensive fossil deposits at Riversleigh in remote north-west Queensland. As he shows me around his lab, Archer points out hunks of Riversleigh limestone bathing in vats of acetic acid, the stone gradually dissolving to reveal the bones within. I see the spine of a giant flightless bird erupting from a rock. "Every one of these is a treasure chest," he says.





In abundant years, bogong moths migrate in such numbers that they "tile" the caves (opposite below) at Mount Gingera, in the Brindabella Range near Canberra. They've not been seen in these numbers for several years.

One of those treasures is Burramys. Archer's team has found more than 500 pygmy-possum bones in Riversleigh rocks 25 to 12 million years old, mainly jawbones and that distinctive, saw-shaped tooth. The fossils are practically identical to the bones of modern mountain pygmy possums. Yet when these ancient ancestors lived, north-west Queensland was carpeted in lush, lowland rainforest. The marsupials' specially-ridged premolar allowed them to scurry around on the ground, cracking open nuts and seeds: filling a niche unoccupied by any other mammal.

It was such a successful strategy that the possums stuck with it, changing barely at all over 25 million years, through numerous wild swings in Earth's climate. Around 12 million years ago, the Riversleigh rainforest dried out, and the possums

disappear from the record there. "The animals that couldn't hack it died. But Burramys is a scrubber," says Archer. "It's a survivor."

Around 2 million years ago, the rainforests spread all the way into today's alpine areas. When the trees retreated, the continent dried out, and, later, settlers cleared the remaining forests for agriculture, Burramys got stranded in the mountains. But by diving into the rockpiles, hibernating over winter, and eating whatever food was available, the species held on.

All this led Archer to believe that Burramys' comfort zone is actually the rainforest – a theory now being put to the test.

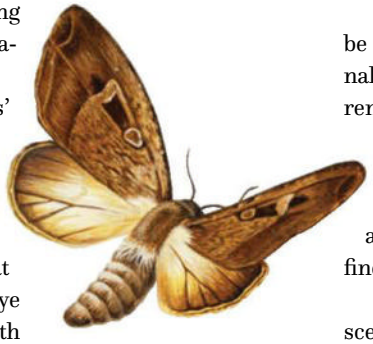
At Lithgow in the Blue Mountains, 145km west of Sydney and 950m above sea level, 14 mountain pygmy possums scamper in cages at a special breeding centre under the watchful eye of owner Trevor Evans. Evans teamed up with Archer to design the breeding facility, which opened in September 2022.

Inside the breeding facility at Secret Creek Sanctuary there are 16 separate enclosures – enough to house 100 pygmy-possums. Each features nesting tunnels enclosed in man-made rocky outcrops, while wall-stickers of snow-covered Kosciuszko attempt to make the possums feel at home. Water trickles down the rock faces, keeping the environment cool. As soon as Evans turned the watering system on, the possums "started to bonk like mad", says Archer – their mating instincts apparently triggered by the moisture. When I visit, Evans pulls out a small drawer in the fake rock wall to show me where the possums nest. To his surprise, all that "bonking" has already produced results: inside the woven stringybark is a mother possum with three tiny, near-blind joeys – the first evidence of successful breeding at the facility.

That promising start has continued, with more joeys born in the months since. And there's other, contemporary evidence that the plan might work. At Cabramurra, one community of possums lives at an elevation of just 1,225m, lower than any other populations. Snow is inconsistent there, suggesting that the pygmy possums may not require it. In fact, Bates' doctoral studies suggest that a key limiting factor for possum populations is a permanent supply of fresh water. Hibernation is hard on the kidneys, and the animals seem to need to drink as soon as they emerge from torpor. In the high country, snow provides both water and insulation against the cold; at these lower elevations, a cool, sheltered rocky creek could become a suitable home for mountain pygmy possums.

Introducing novel species into ecosystems can be fraught, but Archer is optimistic at their original ground-dwelling, seed-eating rainforest niche remains vacant, he says, like an empty glove missing its "ghost hand." To make sure, the scientists will closely monitor ecosystem interactions during the trial releases in fenced areas, and adjust the plan based on their findings.

A key limiting factor for pygmy possums is a permanent supply of fresh water. Hibernation is hard on the kidneys; the animals need to drink as soon as they emerge from torpor.



Broome supports the effort. She also remains sceptical about the possums' prospects in the lowlands. Temperate rainforests also experience drought and bushfire, she points out, "and they're riddled with feral cats", a threat that didn't exist prior to European colonisation.

ABOVE: ZOOS VICTORIA

But Archer believes conservation today requires radical thinking and action. "We've created a situation where we no longer have the luxury of preservation. We have to think about these strange strategies, because there may not be any other solutions. In many cases, that means moving things from what are increasingly unacceptable habitats, to places where they could survive."

Mountain songlines

One full-moon night in the Snowy Mountains in March 1834, Aboriginal women performed a song ceremony, in a place now called Dalgety. "Gundji gawalgu yuri," they sang, in a language that would itself almost be lost in the ensuing century.

Watching the women sing and beat skin drums that early autumn night was a traveling European botanist named Johann Lhotsky. He noted down the melody, and likely asked for help to record the words. Several weeks later, in Sydney, he worked with three "musical gentlemen" to write up sheet music, arranging it for voice and piano forte in the English parlour ballad style. This "Song of the Women of the Menero Tribe" – Menero, now spelled Monaro, is the plateau to the east of the Snowy Mountains – is the first known piece of music ever printed in Australia.

Aboriginal Australians have been singing songs of the high country for millennia – its snows and its possums, its caves cloaked with moths. In their ancient cultures, story and song have the literal power of creation; songlines trace the movements of ancestral beings as they made the landscape, and encode navigational information and traditional knowledge about animals and plants.

Those singing women might have been Jakelin Troy's people, her own Ngarigu ancestors possibly among them. Working with a musicologist, she gleaned the song's story from fragments left in the historical record, and got closer to its original sound by removing European embellishments from the music. While other Aboriginal groups interpret the song's lyrics differently, Troy thinks that given the time of year it was performed – just at the moment when the bogong moths begin to leave the mountains and return to the plains – it's possible the song was part of a ceremony to ensure the snows came and the moths returned the following spring. When she compared the lyrics to the words for snow and Moon in Ngarigu glossaries collected by Lhotsky and other European travellers, as well as her knowledge of neighbouring Aboriginal languages and grammar, the meaning seemed clear to her: send the snow for us soon. Moon, make it snow.

For now, it still snows in the Australian Alps. A late blizzard delayed Broome's November survey, and blocked access to the highest boulder fields. The moths are beginning to return, too. In late 2022, after three years of record-breaking rains, moths once again tiled the caves at Mount Gingera – in numbers approaching half of what they were before the drought.

In early April, the Austral autumn, Troy returned to Dalgety with a group of Ngarigu people. As the fat little possums snuggled into their rocky nests and prepared to hibernate through the winter, as the bogong moths consulted the stars and began their long journey north, the people sang the ancient song to life – caring for their Country, singing the animals onward, calling forth the last of the winter snows.

In the Burramys' high-elevation habitat (opposite top), winter snow cover keeps hibernating possums at stable temperatures and deters feral cats. But snow depth and snow days have been in decline in the Australian Alps since the 1950s. It's one of the reasons that Mike Archer and his collaborator Trevor Evans (opposite, below) set up Secret Creek Sanctuary, in the Blue Mountains west of Sydney. Their hope is to breed Burramys suited to life at lower altitudes – where the fossil record indicates they survived for much of the Miocene epoch. Near the mountainous home of modern Burramys, linguist Ngarigu woman Jakelin Troy (right, at right) believes that her ancestors wrote songs celebrating the annual visits of bogong moths.

KATE EVANS is based in New Zealand. This is an edited extract from *bioGraphic*, from the California Academy of Sciences.

BACKGROUND: RAWF8 / ADOBE STOCK. JET: HYPERSONIX

SONIC

An Australian startup feels the need for speed – and it's going to have a red-hot go, writes **Jamie Seidel**.

Decades of persistence are finally paying off. Australia finds itself ideally positioned to steal the march in the rapidly emerging field of hypersonic flight. But only if it seizes the moment.

Hypersonic flight's been on the wishlist of countries around the world for decades. Now, the US Department of Defense (DOD), has selected Australia-based aerospace industry startup Hypersonix to develop a high-speed aircraft to test extreme technologies operating at the edge of our understanding.

The DOD's decision is no accident. Australian researchers at the University of Queensland, Australian National University and Defence Science and Technology Group have weathered 40 years of election campaigns, defence strategic reviews, university funding grants and international head-hunting to continue making technological progress.

Converging developments in materials science, computing, 3D printing, and aerodynamics mean those years of theory can now be turned into reality. Given recent developments, including the AUKUS technology sharing agreement with the US and UK, that research and development have become incredibly valuable – and an opportunity for Hypersonix.

The company was founded in 2019 with the goal of developing a reusable aircraft capable of flying off an airfield, delivering a satellite to low-Earth orbit, returning, refuelling – and loading up to do the job once again.

In March, its revolutionary DART AE vehicle, powered by a single SPARTAN (Scramjet Powered Accelerator for Reusable Technology Advancement) engine, caught the eye of the US Defense Innovation Unit (DIU). It was chosen from a field of 63 contenders to provide a hypersonic testbed aircraft.

Hypersonix's DART-AE is just 3 metres long. The three examples currently being assembled for delivery next year will be used to measure the performance of heat-resistant materials, components, sensors, communications and control systems under actual flight conditions.

The need for speed

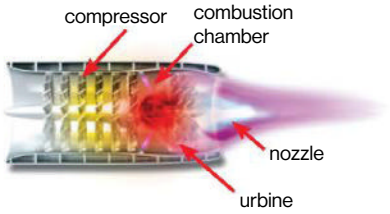
Getting aircraft to go faster and faster is an endeavour that's as old as powered flight. And objects capable of hypersonic speeds – defined as flight through the atmosphere below altitudes of about 90 kilometres at speeds greater than Mach 5 (about 6125 km/h) – have been around for decades. Rockets capable of breaking Mach 5 emerged towards the end of World War II.

Intercontinental Ballistic Missiles (ICBMs) capable of carrying warheads into space before releasing them to fall on their targets at Mach 21 (26,000 km/h) have also existed for decades. But these are ballistic systems: like a thrown ball, they follow simple and predictable up-down trajectories. They don't fly.

Human hypersonics is also not new. In 1961, Yuri Gagarin became the first human in space and also the first to travel over Mach 21 when his capsule re-entered the atmosphere. NASA's space shuttles were hypersonic gliders. But their rudders and ailerons only became effective once they'd slowed to Mach 2 (2700km/h). And the power of the heat generated by extreme speeds was demonstrated to tragic effect on 1 February 2003, when shuttle Columbia disintegrated as it re-entered the atmosphere.

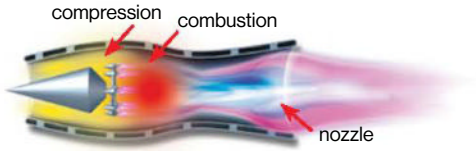
Turbo … Ram … *Scram!*

TURBOJET



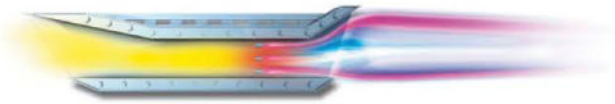
A turbojet takes in and compresses air. Fuel is added and burned in the combustion chamber, and hot gases spin the turbine, charging the compressor. Excess pressure is sent to the nozzle, producing thrust.

RAMJET



A ramjet has no compressor; instead it uses the engine's motion to produce thrust, meaning it can't be used at zero airspeed.

SCRAMJET



Scramjet is short for supersonic combustion ramjet. It operates by burning fuel in a stream of supersonic air and has no rotating parts.

TOP: CLAUS LUNAU. LEFT: JIM ROSS / NASA

USAF / JUDSON BROHMER - ARMSTRONG PHOTO GALLERY

So, when people talk about hypersonic flight, they usually mean ultra-fast craft that can also manoeuvre. This encompasses three different techniques.

Hypersonic glide vehicles are unpowered craft boosted to speed and altitude by an ICBM-like rocket before manoeuvring to their targets.

Hypersonic cruise missiles use smaller rockets to reach hypersonic speeds. But Mach 5 is the ignition point for their air-breathing scramjet engines, which inject small amounts of fuel to sustain their speed over a complex course.

Hypersonic space craft must also reach Mach 5 before their own engines kick in, enabling them to skip along the upper edge of the atmosphere. This combination of immense speed, global range and precision manoeuvrability is unfortunately of great interest to weapons makers, and this has the world's militaries on edge.

Flying things faster and faster, and fast: the F-106 Delta Dart (opposite below) flew at just below Mach 2 (about 2460 km/h) in 1959. Only five years later, the SR-71 Blackbird spyplane had hit the Mach 3.5 (more than 4300 km/h) mark.

> **"Hypersonic flight is the ultimate rocket science. It takes all the complexity and volatility of building a rocket and adds the demand for sustained controlled manoeuvres."**

But is the tech as significant as it sounds?

"I think we don't know yet," says Dr Malcolm Davis, senior space security and strategy analyst at the Australian Strategic Policy Institute (ASPI). "We haven't seen hypersonic weapons used in an operational sense and don't yet really understand just how much of a threat they will be."

Australia in the hot seat

Hypersonic flight is the ultimate rocket science. It takes all the complexity and volatility of building a rocket and adds the demand for sustained controlled manoeuvres.

Essentially, they're building a flaming meteor – and attempting to harness it. The hypersonic craft must navigate. It must contend with turbulence. It must make minute, precise movements to avoid being sent tumbling out of control. Most of all, it must survive the friction generated by extreme speed through the atmosphere.

The USA took the lead in the 1960s with the X-15 experimental rocket planes, which flew at hypersonic speeds on multiple occasions. In

CITIUS, CITIUS, CITIUS

Speed records for powered flight have fascinated humans since the time of the Wright brothers. We've come a long way in 120 years.

October 1904, USA
Wright Flyer III,
Wilbur Wright
60.2 km/h

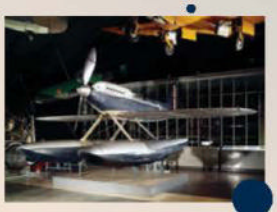
July 1910, France
Blériot, Léon Morane
106.5 km/h

Sept 1913, France
Deperdussin monocoque,
Maurice Prévost
203.9 km/h

Oct 1920, France
Nieuport-Delage NiD 29V,
Joseph Sadi-Lecointe
302.5 km/h

Nov 1923, USA
Curtiss R2C-1,
Lt Harold Brow
417.1 km/h

Mar 1928, Italy
Macchi M.52bis seaplane,
Mario de Bernardi
512.7 km/h



Sept 1931, UK
Supermarine S.6 seaplane,
George Stainforth
655.8 km/h

Oct 1934, Italy
Macchi M.C.72 seaplane,
Franceso Agello
702.2 km/h

October 1967, X-15A-2 reached a top speed of 7274 km/h (Mach 6.7) with US air force test pilot William 'Pete' Knight at the controls. The X-15 program taught the world that controlled hypersonic flight was hard. Very hard.

Emeritus Professor Raymond Stalker laid the foundations for Australia's ongoing involvement when he joined the University of Queensland (UQ) in 1977. He invented a low-cost shock tunnel (dubbed the Stalker tube) capable of simulating the velocities needed to reach and descend from orbit.

"It was that shock tunnel work that became the first way of testing theory and getting practical measurements," says Hypersonix managing director David Waterhouse. "That, in turn, led to the world's first positive thrust from a scramjet."

Scramjets inject fuel into compressed air flowing through a compression chamber at supersonic speeds. Theoretically, they can power a vehicle up to Mach 15 (18,500 km/h).

In 1993, Stalker and UQ's mechanical engineering department were the first in the world to prove this was physically viable. "Then we had the HIFiRE program, which was a very successful series of test flights with different hypersonic capabilities," adds Waterhouse. "So Australia has had a long and large role in developing hypersonics. A world-leading run in many ways."

Professor Michael Smart, who was involved in NASA and UQ research programs, co-founded Hypersonix in 2019. That same year, it successfully ground-tested its SPARTAN hydrogen-fuelled 3D-printed scramjet engine.

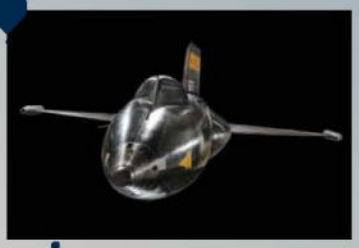
"Australia has got through all of these cycles," says Waterhouse. "And that's enabled a lot of great academic work in terms of taking the theory and measuring the reality of it."

This persistence is on the brink of paying off.

The US has cancelled several hypersonic projects after repeated failures – the most recent, its Air-Launched Rapid Response Weapon project, just this April. As a result, the Pentagon is hoping to leverage the AUKUS technological exchange agreement to help get its programs get back on track.

FROM TOP LEFT: WIKIPEDIA; US LIBRARY OF CONGRESS; YOUTUBE; SAN DIEGO AIR & SPACE MUSEUM; US NAVY; DELCAMPE.NET; LONDON SCIENCE MUSEUM; HISTORIC WINGS.

Oct 1947, USA
Bell X-1, Capt Chuck Yeager
1078 km/h
First flight to break the sound barrier



Oct 1967, USA
North American X-15, William 'Pete' Knight
7274 km/h
Current official world speed record for a crewed, powered aircraft

Nov 1981
Space Shuttle Columbia, Joe H Engle
28,000 km/h
Fastest manually controlled flight in Earth atmosphere

June 1947, USA
Lockheed P-80R Shooting Star, Col Albert Boyd
1003.6 km/h

Nov 1945, UK
Gloster Meteor F Mk.4, H J Wilson
975.9 km/h

Aug 1986, UK
Westland Lynx, Trevor Egginton
400.8 km/h
Fastest helicopter

Feb 1996, Atlantic airspace
Concorde, Leslie Scott
2010 km/h
Fastest passenger plane flying a regular route

"It's very reliable, it's very inexpensive to build. And literally, you can fly it back – use a toothbrush to scrape off any unwanted grit – and then fly it again."

"They've got to catch up," says Waterhouse. "China alone is doing 90 launches for every single US launch. And of the US launches, 50% of them fail."

Extreme machines

In powered flight perhaps more than any other field, what's extreme today may be normal tomorrow.

In 1944, test pilots were pushing their piston-engined aircraft to the edge of the sound barrier – often with fatal results.

The sound barrier was breached in 1947 by Chuck Yeager flying the experimental X-1 rocket plane.

Less than two decades later, continuing improvements in jet turbines and aerodynamics enabled the development of the SR-71 Blackbird spyplane – which took off and landed like a regular aircraft (the X-1 and later rocket planes were dropped mid-air from "mother ships" to begin their flights) – and routinely reached speeds of more than Mach 3 (more than 3700 km/h). It's taken another 60 years to reach the point where the hypersonic barrier can be realistically challenged.

Waterhouse says the SPARTAN engine represents the convergence of three new technologies: powerful and accessible supercomputer modelling, additive engineering producing new materials, and the arrival of the hydrogen economy.

"It's cheap and cheerful," says Waterhouse of modelling tech. "What would have taken me a week to run just a decade or two ago I can now do

FROM TOP LEFT: NASA; PUBLIC DOMAIN; NATIONAL AIR & SPACE MUSEUM; US MARINE CORPS; NASA; BWP MEDIA/GETTY IMAGES.

in 15 minutes. And it's affordable to even small companies."

At the heart of Hypersonix's scramjet technology is how its shape contains – and exploits – different shockwaves generated by high-speed flight. When combined with hydrogen, the explosive interaction generates thrust.

It's 3D-printed. And its only moving part is a valve to the hydrogen tank.

"Because of its fixed geometry with no moving parts, it's very reliable," says Waterhouse. "It's very inexpensive to build. And literally, you can fly it back – use a toothbrush to scrape off any unwanted grit – and then fly it again".

The DART-AE prototypes supplied to the US will have engines 3D-printed from the common rocket metal Inconel 718. "[It's] been around since the days of the Saturn V [Moon launch rocket]" says Waterhouse. "But now I can 3D print it and do things with it you could never imagine. And there's the whole additive engineering thing. They're combining materials in a way that you couldn't do just five or 10 years ago."

Even when cooled by hydrogen circulating through the engine's structure, the craft's maximum speed is capped at the point it hits 2000°C – a temperature generated by Mach 7 (more than 8600 km/h) flight.

But Hypersonix is aiming to produce a reusable scramjet engine capable of reaching Mach 12 (more than 14,800 km/h). It's testing a version of the SPARTAN made from modern High-Temperature Ceramic Matrix Composites (HTCMCs).

"The ceramic matrix composite is good for temperatures above 1800°C for sustainable operations," Waterhouse explains.

As for hydrogen: "It's great," says Waterhouse. "It burns clean. It doesn't leave coking or anything behind. And that enables reusability. But the great thing about the hydrogen economy is you can buy fuel tanks off the shelf now. A few years ago, building them in-house would have cost heaps. And I'd have to blow a bunch of them up before I was certified to use them."

But sustained, controlled hypersonic flight remains at the edge of technological capability.

"The risks and the technological challenges of these vehicles will probably mean we won't get hypersonic airliners anytime soon," says Davis. "I would love to see us get back into supersonic air travel first in a more cost-effective manner, but

Hypersonix co-founder Professor Michael Smart (below), from the University of Queensland, oversaw testing in 2019 of the SPARTAN 3D-printed scramjet engine.

LEFT: UNIVERSITY OF QLD. BELOW: HYPERSONIX.

"The laws of physics haven't changed much in the past 40 years. But the technology has. And it will continue to do so. We can expect better fuels, better materials, and lighter weights."

I'm sceptical about hypersonic for now."

The development of hypersonic weapons is another matter. "I think everyone is still working towards a hypersonic cruise missile," says Davis. "Once it's launched, it's almost impossible to stop because it is going so fast and changing course at the same time.

"If the US is basing its military strategy on the projection of power at sea through naval carrier battle groups, and you can sink those carriers before they get anywhere near the scene of action – then the age of the carrier is over in the same way as the battleship [was superseded by aircraft carriers]. That's significant."

Hypersonix on a mission

"At the end of the day, we're not a defence company," says Waterhouse. "We're a deep tech company. We're looking for applications for hypersonic flight and scramjets in particular. That's our core technology – reusable, hydrogen-powered, fixed geometry, high-performance scramjet engines.

"When jet engines were first introduced, defence got them off the ground. Now they're part of our everyday lives. We want to move towards aircraft-like behaviour for accessing space."

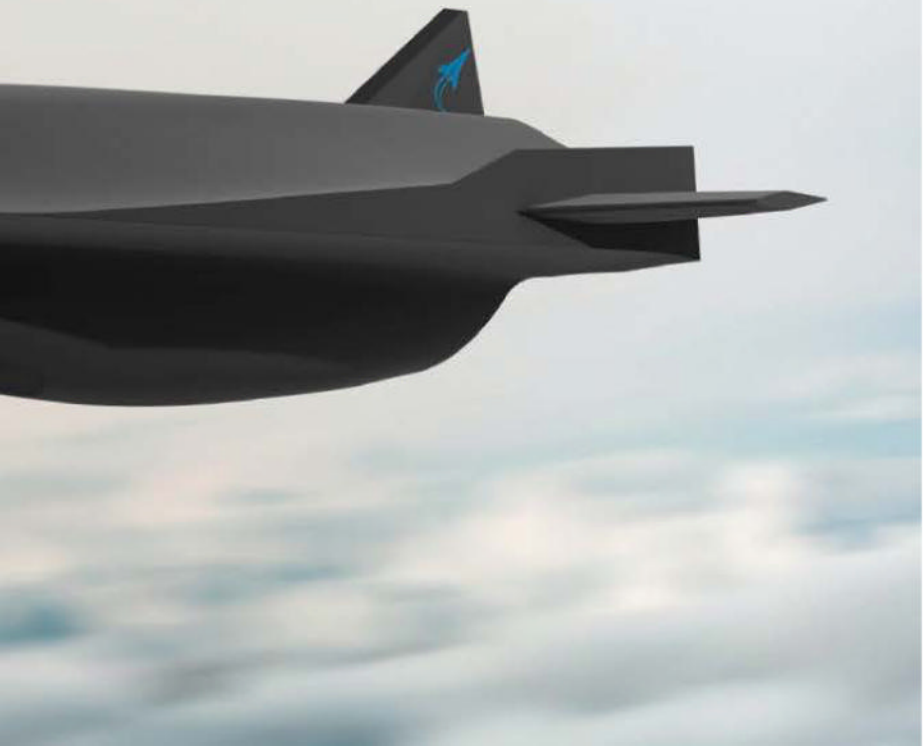
It's a continuum of technology.

What you do today is less than you can do in 10 years. And 20 years beyond that.

"We're standing on the back of giants," Waterhouse says. "The old NASA studies did a lot of the work. And the laws of physics haven't changed much in the past 40 years. But the technology has, and it will continue to do so. We can expect better fuels, better materials, and lighter weights. It all works together towards making all this more achievable."

Concorde Mk II? The Boom Overture (above) is a concept supersonic passenger plane with similar performance characteristics to the UK-French Concorde, which flew commercially from 1976 to 2003. The Overture's proposed top speed of Mach 1.7 is just over Mach 5 short of the top speed of Hypersonix's pilotless DART-AE (below).

RIGHT: UNITED / BOOM TECHNOLOGY



Hypersonix's plan to develop its Delta-Velos space plane involves a staged approach. Early flights will be carried vertically into the atmosphere and up to Mach 5 ignition speeds by rockets. New Zealand's Rocket Lab will be boosting Hypersonix's DART-AE testbed aircraft in this way with its HASTE Electron rocket next year.

"But if you look at the technology, there are two very interesting possibilities," says Waterhouse. "Reusable rocket planes could quite easily reach Mach 5. And while traditional jet turbines generally cap out at Mach 3, a new technology pre-cools the air it sucks in to produce extra thrust. Either way, our scramjet can piggyback one of those and jump off at Mach 5."

He adds that such a reusable two-stage-to-launch system would reduce costs and increase flight frequency. "That allows you to start pushing commercial applications and getting price points down. And then, eventually, who knows – you could even get on a plane and fly from Sydney to London in 2.5 hours."

Will these remarkable craft be Australian made?

"I think it's really a difficult time for small businesses in Australia at the moment," says Waterhouse. "We're fortunate we've got these orders from the US."

Ultimately, he says, it's just business.

"We're pushing Australia," he adds. "We would love to make the whole thing here in Australia. But if we can't do it here, we'll do it in the US. I'm running a company and must take care of my shareholders. If someone offers us a bucket of money to manufacture in the US, that's where we'll go."

JAMIE SEIDEL is based in Adelaide. His most recent story for *Cosmos*, about a day on the Moon, appeared in Issue 98.

A menagerie of robotic

They're cute and nostalgic, but do robot animals have more potential than just as talking toys? **Petra Stock** talks to their researchers about the tricky combination of function and form, and how we might use it to our future advantage.

CENTRE: THE WASHINGTON POST / GETTY IMAGES

The baby harp seal is propped on the table in front of me. The pup's eyes are closed. Its dormant, rotund, furry body looks soft and inviting. On hearing its name – "Paro" – the seal lifts and tilts its head. It opens wide, deep-lagoon eyes, and blinks.

Unable to resist, I reach out and gently scratch Paro's neck. I stroke its back and whiskers. The seal pup leans into my hand, and its body rumbles like a purring kitten.

"Oh," I hear myself say, as I exhale and allow the creature to nuzzle its warm, soft body against mine.

Pleased to meet you

Like people, first impressions matter for robots. Human-robot interaction researcher Nathan Dennler says when people meet a new robot, they instinctively relate it to a familiar experience – a character or object it reminds them of. Those metaphors act as an anchor point for how they expect a robot to behave, and an indicator of its capabilities.

Dennler works in the Interactive and Collaborative Autonomous Robotics (ICAROS) lab at the University of Southern California, USA. He and colleagues recently assembled a collection of 165 interactive robots, to better understand the ways people respond to a robot's physical form.

They asked nearly 2,000 participants across three surveys to describe and rank a range of humanoid, animal-like and mechanical robots. Participants were asked to choose metaphors to describe each one and their expectations for its social interactions, including warmth, competence, gender, social role, likeability and function.

"We wanted to figure out how people conceptualise those robots," he says.

Science fiction has perpetuated a fascination with humanoid or droid-like forms, but Dennler's research suggests zoomorphic designs offer certain advantages. People perceive animal forms generally as the most warm and friendly type of robot, and least discomforting, he says.

For instance, participants in Dennler's study rated Paro highly in terms of warmth, alongside Leonardo – another small, tactile robot which looks like Gizmo from the movie *Gremlins*.

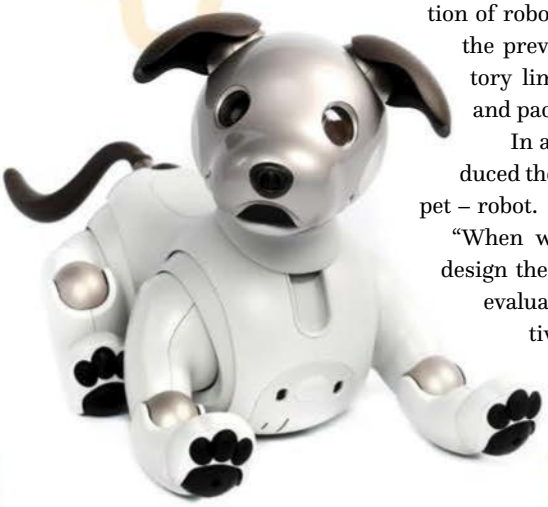
The machine's physical form is about more than looking cute, or cool, or futuristic. Dennler's research shows design breeds expectations, which boosts the human experience when those presumptions align to the robot's capabilities and intended purpose.

When Paro's creator, Dr Takanori Shibata, first thought of designing his "artificial emotional creature", he pictured a big egg shape covered in fur: something nice to touch. Now chief senior research scientist at Japan's National Institute of Advanced Industrial Science and Technology, Shibata was among pioneers developing personal robots in the early 1990s. At the time, his conception of robots was in stark contrast to the prevailing fixation on fast factory limbs for welding, assembly and packaging.

In a 1996 paper, Shibata introduced the concept of a personal – or pet – robot.

"When we think of machines, we design them as convenient tools and evaluate them in terms of objective measures, such as time, accuracy and energy," he

The modern petbot cohort includes snuggly Paro (above), puppy-like Aibo (below), a duck-like bot that bops (opposite bottom) named Keepon, and spider-like Hexon (opposite top). Furry Furby (opposite centre) first appeared in 1998.



animals

FROM TOP: NURPHOTO; THE WASHINGTON POST / GETTY IMAGES.

wrote. “We may search for the best solution. This is a rational way and quite reasonable in engineering.”

Instead of precise industrial automatons enslaved in factories, Shibata pictured personal robots living at home alongside people. “They might hold it or put it on their lap, while stroking, watching TV or talking with others,” he explained.

Shibata’s egg idea hatched into an animal. In designing Paro, Shibata considered three possibilities: a baby seal, or the more familiar form of a dog or cat. To test the concept, he made robots modelled on all three options and asked people to evaluate them. Dogs and cats were well known. But this established certain expectations – to purr, lick, play fetch or feed – which the robot couldn’t always live up to.

A social robot engages with people’s emotions. Human-robot interactions might simulate positive feelings like affection, happiness and love, or negative responses like anger, sadness and fear and will be evaluated accordingly, Shibata prophesised.

“Human beings are not machines. We have ‘mind’. The emotions have been considered to be important.”

Electric dreams

When you picture a robot, what comes to mind?

The hard and shiny almost-human kind like C3PO from *Star Wars* or evil Megatron from *Transformers*? Or, the squat, droid designs of Daleks?

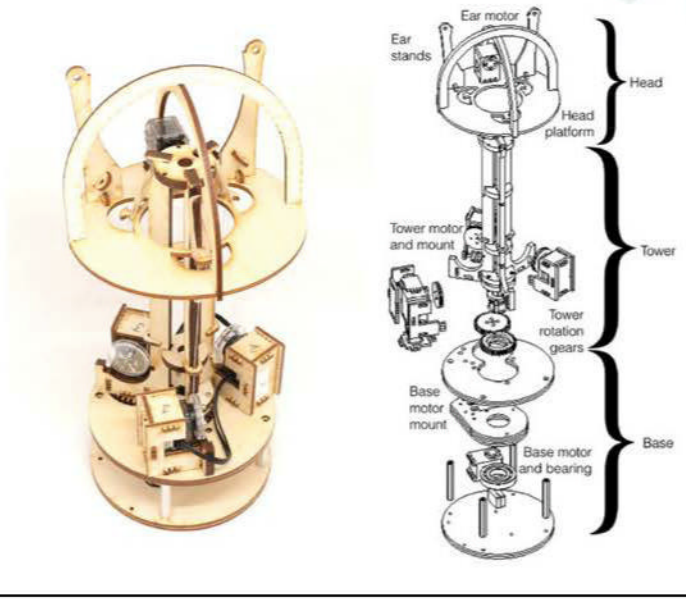
The term “robot” is loaded with stereotypes and expectations. Science fiction has primed us to overestimate the technology, and often to expect the worst. We hear *robot* and think of the Terminator, or an uprising of killer machines just over the technology horizon; maybe also artificial intelligence surveillance systems tracking our every move, prompting fear and suspicion.

But does that say more about the robots, or about us?

Paro was developed during the first wave of social robotics in the late ’90s and early 2000s. It was a golden age for zoomorphic robots – mechanical objects designed to look like animals and programmed to interact with people in a social way. The strangely furry and owlish Furby, sleek plastic puppy Aibo, bopping yellow duck Keepon and baby dinosaur Pleo all made their way off shelves and into the hearts of a generation of wide-eyed kids and kidults, including me.

Since then, more than 340 different social robots have since been created. Most are prototypes, made for research purposes only. Fewer than half ever became commercially available, and about a third remain in production.

Inside Blossom



In the second period of social robotics – between 2006 and 2012 – creative critters gradually gave way to a population boom of human-like models, as roboticists chased the technical challenge of replicating themselves. Some took things literally, creating machines with eerily hominoid epidermis, hair and facial expressions. Others came skinned in hard, white plastic.

But as the anthropomorphic wave subsides, a more beastly brood is making a comeback: like the soft-bodied Tega, a red and blue blob with a tuft of troll hair; or the blue-eyed Photon, somewhere between a bat and a tricycle; or the hard-shelled Hexa that creepy-crawls on six legs. Increasingly, form is now following function. Insectile Hexa can navigate various terrains. Friendly Tega charms children to assist with early literacy. Animal forms bring other benefits too.

ABOVE: SUGUITAN, HOFFMAN X2

In general, people don't ascribe these animate objects a gender, says Dennler.

Zoomorphic robots avoid concerns about bias and stereotyping arising when designers or users attribute a specific gender to a robot. Problems can arise, for example, if a feminine-looking robot is assigned a stereotypically female role, or assigned to servant-like tasks.

But he advises that not all robots can or should be animals. It's important to align a robot's functionality with people's expectations based on its physical form.

"For the robots that look like animals, people were expecting them to be fulfilling the role of a pet. Something like a companion, that maybe doesn't do the dishes for you," Dennler says.

Dinosaur designs

Kate Darling's home has become a gathering place for baby robot dinosaurs.

Darling is a research scientist at MIT Media Lab, and an expert in human-robot interaction and ethics. Her home is a refuge for lost Pleos, the robot designed by Innvo Labs to emulate a week-old baby sauropod. Darling houses seven of these robot dinosaurs, though only the one she calls 'Mr Spaghetti' remains functional.

'Yochai', 'Peter', 'Bones McPleo' (an early – and slightly disturbing – skinless, skeletal prototype the company gave her) are heaped next to three other nameless and broken shapes, sent by owners hopeful she might give them a second life.

In her book *The New Breed*, Darling argues people should stop comparing robots to humans and think of them more like animals instead.

"People were expecting them to be fulfilling the role of a pet. Something like a companion, that maybe doesn't do the dishes for you"

"It's always struck me in our conversations around robots and artificial intelligence that we like to subconsciously compare this technology to humans. So, robots to people and artificial intelligence to human intelligence," she tells me.

"I think that's the wrong metaphor. Artificial intelligence doesn't think like human intelligence. It perceives the world differently, understands the world differently."

Darling's not suggesting animals and robots are the same either. But, she says, thinking about them that way allows the chance to consider new possibilities for what robots could be.

One practical reason for designing robots like animals is biomimicry – borrowing ideas from nature. It's useful when thinking about locomotion and ways that robots could navigate different parts of the planet – for example, a fish-like robot designed for moving underwater, a featherweight robot fairy for travelling on the breeze, or a snake form for navigating narrow spaces.

Another is our own preconceptions.

Darling's Pleos are based on a half-size baby Camarasaurus, and benefits from the lack of judgement about its capabilities or behaviour. After all, no human has lived alongside a real one. Like Paro the seal, this helps the dino-bot bond with humans on an emotional level, without the expectations of a more familiar fur-child.

According to its maker's website, the dino-bot progresses through four life stages as humans interact with it. From opening its eyes and learning to stand, it begins to recognise its name and explore its home environment, making goofy "haw" noises and demanding human attention. As its personality evolves, Pleo even develops likes (sugar cane snacks and pats) and dislikes (it cries if punished).

Animal robots can be

SEAN GALLUP / GETTY IMAGES

Tega (opposite bottom), which hit the market in 2016, helps children improve their language skills. Blossom (opposite top) is a DIY petbot – knit or crochet your own "skin" to cover its 3D-printed internals (opposite centre). The more one talks to Pleo (below), first released in 2006, the more advanced it becomes. As its personality evolves it responds to its name, demands attention and even develops a fondness for sweet snacks.

delightful, but Darling warns that this means care needs to be taken with how they are deployed.

Out of context, they can freak people out and send things "completely off the rails," she says.

"We know from research and human-robot interaction that people have a very visceral response to certain designs of robots, because we subconsciously treat robots like they're living things."

By way of example, she says, public responses and reactions to the Boston Dynamics robot, Spot, tend to vary wildly depending on its use.

Spot is a crayon-yellow quadrupedal robot that many people consider to be a dog.

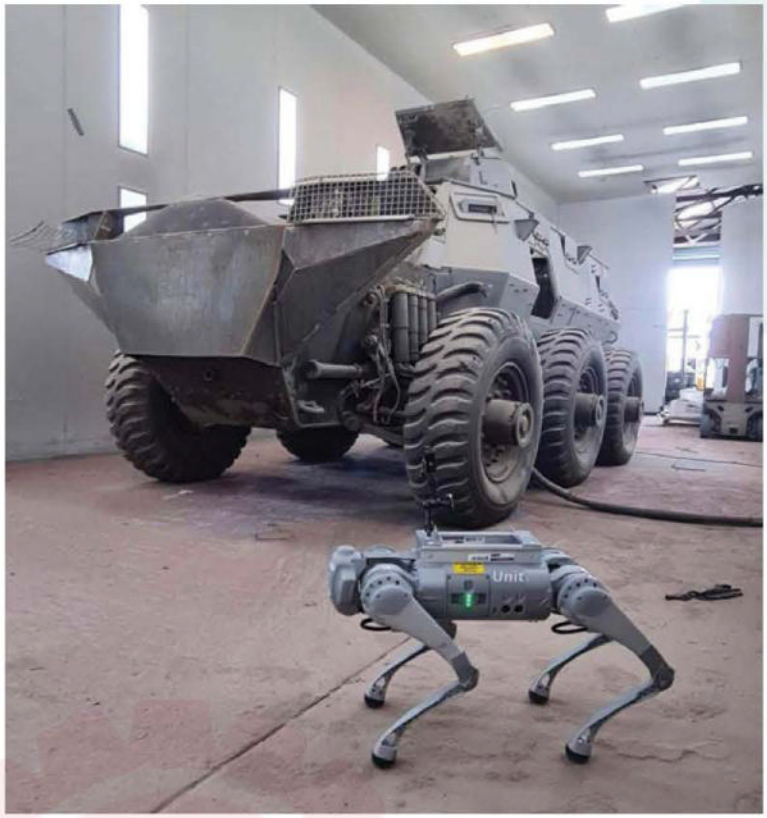
"Depending on the setting, people have either enjoyed having the robot around, or they have found it very upsetting," she says.

When police in New York city trialled using Spot for surveillance and CCTV in hazardous environments, including hostage situations, it repelled many city residents.

"It's creepy, alienating and sends the wrong message to New Yorkers," says a spokesman for NY Mayor Bill de Blasio, capturing the public response.

In Australia, a young woman in Brisbane's Fortitude Valley had a similar response when coming across a prototype military-grade robotic dog out walking with its engineer at 2:30am According to media reports, her immediate reaction was to give 'Stampy' a sturdy kick to its front sensors, causing thousands of dollars in damage.

It seems we want our animal robots to be with us rather than against us.



Dog-like bots don't please everyone: a passerby gave military-grade prototype Stampy (above) a kick to the sensors in Brisbane in January. Its owner estimated the damage bill at $2500.

Bringing bots closer to home

Little robot Blossom is hardly more than a ball of wool, wooden ears, small motors, rubber bands and a series of 3D-printed gears and platforms waiting to be freed from a rectangular mould.

"We have so many expectations of robots. By stripping this away and playing the expectations down, then people could form a better bond."

"When you build it yourself, you value it more," says Blossom's creator Dr Michael Suguitan, who developed the robot as a doctoral student at Cornell University, USA, with collaborator Dr Guy Hoffman.

Blossom is a handmade, DIY robot. Its internal skeleton can be 3D printed, its movements and behaviours programmed by open-source software. The robot's "skin" is crocheted or knitted; depending on your crafting abilities and choice of appendages, the robot could be a rabbit, a bear or even a squid.

"The whole ethos of the project was questioning many things about how robots are designed now," Suguitan says. "If you Google search robots, you'll see a bunch of robots that look like the robot Eve from WALL-E. They often have hard, white, plastic exteriors, a bit like consumer electronics."

He wanted Blossom to be the antithesis of this idea.

"We have so many expectations of robots that look like this [...] Eve from WALL-E, who's a super futuristic, super smart, intelligent agent," he says. "And robots, [...] they're really not to that level yet. I think by stripping this away and kind of playing the expectations down, then people could form a better bond."

"If they're more animal-like then it opens up this whole new idea space of possibilities and different roles that they can play."

Beyond roles as toys or substitute pets, aged care is one area where robot companions are being used relatively extensively, to help older people who are lonely and disconnected, or who miss having animals in their lives.

Dr Simon Coghlan, a philosopher with a

STAMPY DOG / FACEBOOK

background in veterinary science who now researches the ethics of digital technologies and robotics, has a few concerns; including one he defines as "deception".

"The robots are designed to mimic or replicate the kinds of behaviours and appearances of living animals. The closer to the real thing they are, the more likely deception will become an issue," he says.

Another issue he flags is "consent": whether the person being given a robot has understood the technology and agreed to its use, especially if a robot is collecting data or being used for surveillance.

But Coghlan can see that, a bit like living ones, robot animals might offer some comfort to people.

"Studies show some people – not all – do get a lift in spirits from interacting with these animal-like things, these robots," he says. "And so [they produce] those kinds of emotional effects on people that maybe reduces their loneliness."

Nonetheless, he cautions, the relationship can't be mutual.

A living animal, "a creature with sentience or an inner life", can recognise its owner, miss them, try to comfort them, Coghlan says.

Whereas a relationship with a robot animal? "It's completely one-sided."

A cross between a bat and a tricycle, Photon (above) is an educational bot, designed to help teachers during everyday school activities. Paro (below) powers up by a mouth socket that resembles a baby's dummy.

Role models

Paro is accepted in the US, Europe and Australia as a therapeutic tool or "biofeedback medical device" in aged care, particularly with dementia patients.

After the first-generation Paro in 1998, the seal robot was commercialised in Japan in 2005. There are now more than 7,000 Paros in use across 30 countries, including Australia. The robot's design is robust and durable, and Shibata is aware of some owners who have been living with Paro as a pet for more than a decade.

Under its white pelt exterior, Paro's hand-manufactured robot skeleton contains an internal artificial intelligence system connected to touch, light, audio, temperature and posture sensors. Speakers replicate a seal voice sampled from real baby harp seals, and an internal heating system makes its body feels warm to touch.

The baby harp seal robot requires only electricity to function, with power supplied to the pup's mouth via a plug which looks like a baby's dummy.

In one sense the robot seal is advanced technology – it can learn a new name, and adapts its behaviour to be better liked by human companions. And, unlike many modern technologies, Paro does so without software updates, WiFi connection or the usual amassing of personal data to be shared with the cloud or third parties. Shibata says that's because he wanted Paro to be robust and durable over the long term, and owners "do not want to be bothered by technical, privacy or security issues".

Meeting Paro takes me back to my '90s childhood, a time when I considered the baby harp seal to be the pinnacle of cuteness. As a child growing up in suburban Adelaide – about 20,000 kilometres away from the real animal's North Atlantic home – a large, framed photograph of an alabaster seal pup hung on the wall of our suburban study, the computer room.

It was also a time when new technology inspired awe and delight.

Today, it's near impossible to separate the march of tech progress – new platforms, apps, devices, AIs, robots – from the accumulated wounds of pervasive creepiness, data gluttony and algorithmic deceptions, constantly surveilling and intruding unwelcome into our private lives. I know this, but as this animatronic harp seal mews and snuggles, I feel joy and warmth.

Unlike humanoids or droids, zoomorphic robots like Paro can be comforting. People – even me – are inclined to accept and warm to them, so long as they're on our side.

The robots we see in popular media – the Terminators, battle droids – reflect our fears for the future, but it's only one possible path that robotic design and engineering might go down. It's as easy to create a vision of loyal C3P0 and R2D2 helpers – and equally possible to consider a world in which dinosaur-inspired harvest helpers and spider-engineered search and rescue bots are the norm. Just don't expect them to do the dishes.

YAMAGUCHI HARUYOSHI / GETTY IMAGES

PETRA STOCK is a journalist at *Cosmos*. Her story on seeing emotions was in Issue 98.

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ZEIT

Second Life's International Spaceflight Museum is a must-visit for space exploration tragics. The virtual museum has exhibits including past, present and future spacecraft and hosts events about space travel. Best of all for your metaverse avatar: you can ride a rocket into space. Until the promise that generative AI so recently brought to creating virtual spaces, Second Life, launched in 2003, remains the best example of the possibilities of combining technology and community.

LINDEN LAB / SECOND LIFE

GEIST

› Science meets life

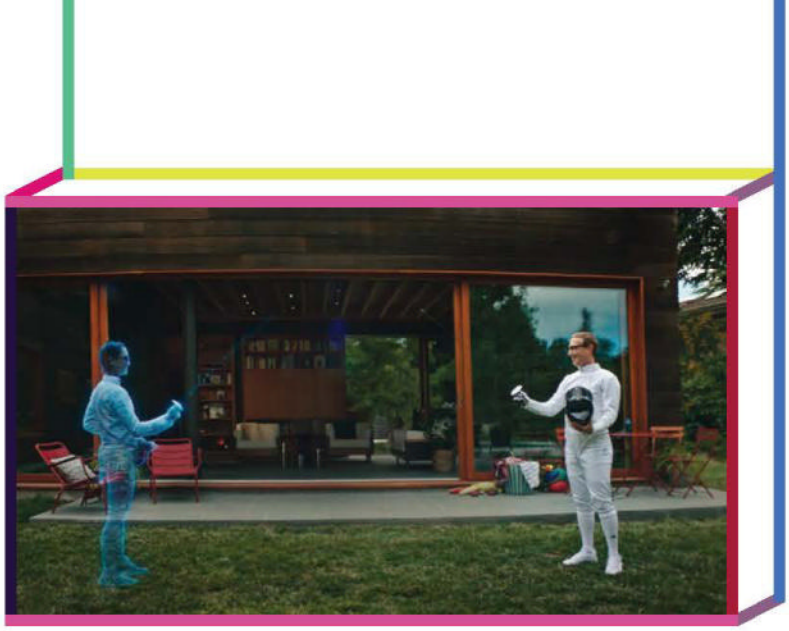
(BACKGROUND) SHUOSHU / GETTY IMAGES. (OTHERS) SECOND LIFE, MIDJOURNEY, DALL-E, FACEBOOK/META, DREAMFUSION

The long march to the syntheverse

Could today's explosive developments in "generative" artificial intelligence transform how we come to experience the world over the next 20 years? To understand why that might happen – and how – we need to look back across the past 20 years, says **Mark Pesce**.

It may be hard to credit, but when *Cosmos* Issue 1 appeared in 2005, the metaverse was in a brief renaissance, its second life. Its first life ran from the 1992 publication of Neal Stephenson's cyberpunk masterwork *Snow Crash* – which gave us the word "metaverse", describing an environment where billions electronically project themselves into a 3D world, a space in which seeing and being seen generates the social capital driving a decaying mid-21st-century America.

Wickedly funny, but almost wholly dystopian, *Snow Crash* nevertheless provided a defining vision for a generation of engineers, product designers and entrepreneurs who imagined the metaverse as the next big thing, hot on the heels of a brand-new and white-hot World Wide Web. Products poured out, most of them slow, many hard to operate, and all of them lacking any driving reason to use – many people tried Active Worlds, one of the most popular early metaverse tools, but most abandoned it to text-based messengers, like ICQ. Each attracted a small community of fans, yet all eventually shuttered, as the spigot of venture capital money funding the early metaverse went dry.



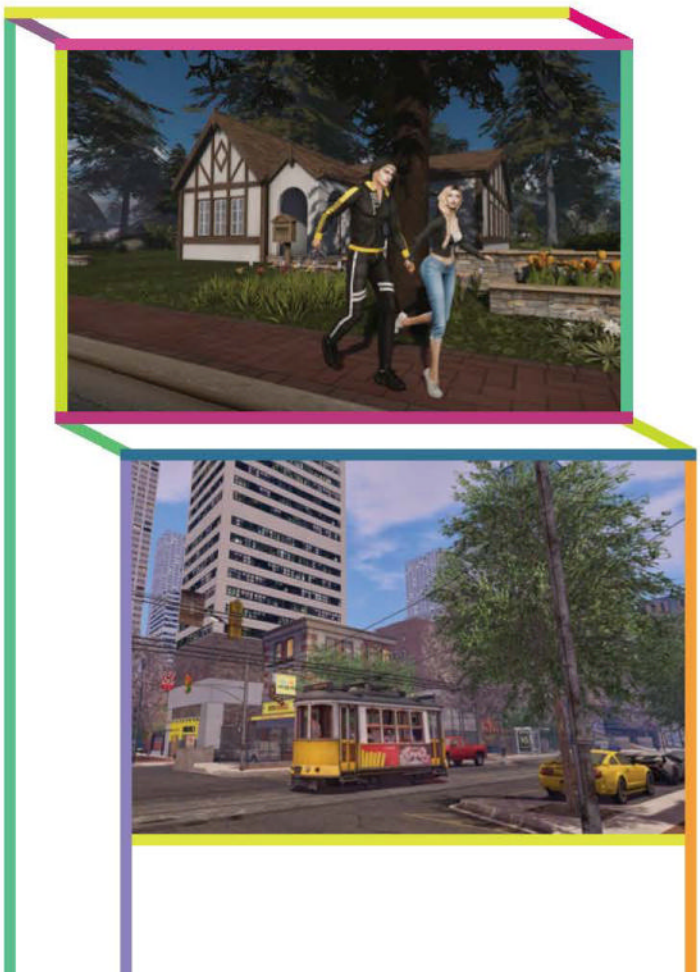
Was the metaverse dead – or merely "pining for the fjords"? For half a dozen years it looked gone for good, until Philip Rosedale's Linden Labs launched Second Life. In a bit of nominative determinism, it breathed life into a dead metaverse. For a brief moment in time, Second Life became the most talked about app in the world, with millions of signups, commercial "spaces" owned by firms such as IBM, and more than enough revenue to keep the whole thing rolling along years after attentions had shifted to Facebook, Twitter and TikTok.

Second Life's still around, with about a million monthly users – many of whom, because of distance or infirmity, have a real need to connect socially through a screen – but it's passed out of popular consciousness.

After its second death, the metaverse became the favoured punchline to many a joke about the failures of Silicon Valley culture, venture capital, and Net entrepreneurs. Most people had forgotten about the metaverse until 28 October 2021, when Mark Zuckerberg rebranded Facebook, the behemoth of social media, as Meta Networks.

Although some in the media found themselves caught up in Zuckerberg's hype about a new world where we'd all be working and playing every day, others wondered whether the basic problems that had kneecapped the metaverse twice had been solved – or even *could* be solved. One of these problems appeared to be fundamental: beyond some wild plans for "office" spaces and "entertainment", no one (even at Meta!) seemed to have a clear vision of why anyone would ever use it.

Perhaps the most successful metaverse to date, Second Life (below) has had 70 million accounts since its launch in 2003. Despite the obsession of Mark Zuckerberg (above, right), Facebook's Meta has a reported 200,000 users with the majority leaving in less than a month.



Meta's sceptics proved prescient: despite spending about $US40 billion ($62 billion) to develop the metaverse, by early 2023 Zuckerberg was executing a pivot toward the next new hot thing, generative AI. When Apple introduced its Vision Pro headset in June of 2023, they never even whispered the M-word, instead stressing its purported abilities to "augment reality", focusing on the real world – precisely because the imaginary world had proven so frustratingly illusory.

Ironically, it's only after this third death that it becomes possible to glimpse what the metaverse of 20 years hence might look like – or rather, what it might be able to do.

Build it, and they will come?

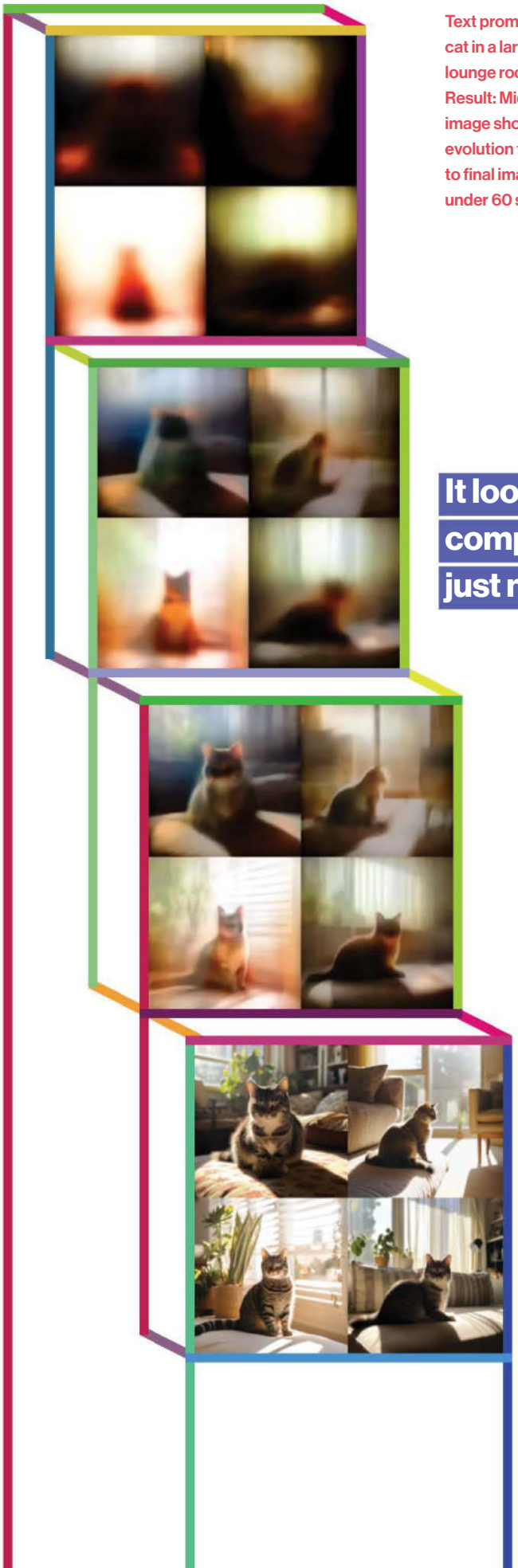
What to do in the metaverse turns out to be the most important question of all. Until people have a reason to use it – because it provides something unique and uniquely valuable – no one will use it.

This is where AI rides to the rescue.

From the middle of 2022, advancements in artificial intelligence have felt dizzying. Although it appeared as though everything arrived at once, each innovation represented years (in some cases, decades) of research work. The first of the innovations that came to popular attention were known as the "diffusers" – programs that translate text prompts into images, "painting" as directed by the prompt.

A diffuser starts with "noise" – a patchwork of tiny, random white and black squares to the eye – and then makes some changes to the noise. Those changes get compared with an abstract model of "cat" or "rocket ship" or what have you – a model generated by exposure to tens – or even hundreds – of millions of images, each labelled cat or rocket ship and so forth.

LEFT: SECOND LIFE. ABOVE: FACEBOOK/META



MIDJOURNEY

Text prompt: "A small cat in a large sunlit lounge room." Result: Midjourney image showing the evolution from noise to final image in under 60 seconds.

That mapping between labels and images allows the diffuser to go from noise to a fully realised (and fully synthetic) image. A diffuser can't do this in one go. Most diffusers have to iterate many times – 25 times, and sometimes more – to achieve the final state. Watching process, you can see the image slowly emerge. It looks a lot like magic – as if the computer is painting – but it's really just maths and a well-trained model.

In May 2022, when OpenAI released its own diffuser, DALL-E 2, to the public, it heralded a new era of visual imagery; weird, synthetic forms (sometimes with disturbingly incorrect numbers of hands, fingers, paws etc) generated by people typing a bit of text into a box. This generative artificial intelligence emphasised the computer as a creative tool – not merely the stylus of a Photoshop,

It looks a lot like magic – as if the computer is painting – but it's really just maths and a well-trained model

which needs to be managed precisely and continuously, but the palette and expressiveness of an artist. Is a diffuser thinking? Is it creating? No – but it does look as though the computer both thinks and creates.

Like many others, I found myself absolutely entranced by these diffusers. Although I'm very comfortable in the creative realm of words, I've never had a talent for – nor training as – a painter. To be able to go from text to image felt magical – and very useful. Others felt the excitement and began to share their own tips for effective prompts – simple bits of text that somehow got the diffuser to turn out some amazing imagery.

One of these prompts showed me the shape of the future: "Tiny cute isometric living room, soft smooth lighting, blue and purple scheme, soft colours, 100mm, 3D blender render."

Feed that into DALL-E 2, its competitor Midjourney (which has an aesthetic that makes almost every image look a bit like a 1970s progressive rock album cover), or the free and open-source Stable Diffusion, and you get something that looks very much like a photograph of a living room, well-lit, tastefully arranged, decorated in an attractive colour scheme.

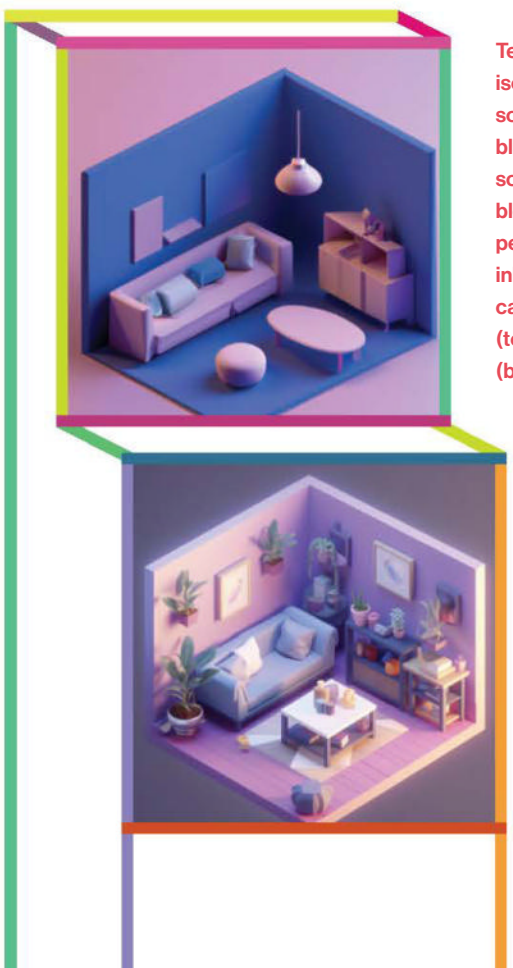
All of it, I noticed immediately, looked very much like a precise 3D model from a Pixar film; a little corner of the metaverse, generated by a diffuser. Which got me to thinking – if diffusers can create 2D images of 3D objects, could they generate 3D objects themselves?

An added dimension

An answer wasn't long in coming. At the end of September 2022, a joint University of California and Google research team published a paper describing Dreamfusion, a diffuser capable of going that last step, translating a prompt text-to-3D. Best of all, it worked from the diffuser imagery: "Our approach requires no 3D training data and no modifications to the image diffusion model, demonstrating the effectiveness of pre-trained image diffusion models as priors." Rather than requiring training on millions of real-world 3D objects, Dreamfusion can rely on a 2D image generated by a diffuser to generate a 3D object.

Although not yet widely recognised, Dreamfusion provides a solution to one of the biggest shortcomings of the metaverse – a lack of content. Everything in the metaverse has to be built for the 3D world, a process that tends to be laborious, expensive, and short of good talent – a competent 3D artist will make upwards of a hundred dollars an hour banging out content for a video game, and far more if they're working at a film studio. Dreamfusion sidesteps all of that hard work. The prompt "a DSLR photo of a squirrel wearing a purple hoodie wielding a katana" works exactly as described.

Dreamfusion means the barrier to creativity in 3D has crumbled. Anyone can create pretty much any 3D object they can describe in words.



Text prompt: "Tiny cute isometric living room, soft smooth lighting, blue and purple scheme, soft colours, 100mm, 3D blender render." Pixel perfect and ready to inhabit, these results came from DALL-E 2 (top) and Midjourney (bottom).

The metaverse can now be filled with particular, meaningful and personally crafted objects, representing a big step toward meaning. But objects tell only half the story, because all objects reside within some sort of space – a synthetic office, classroom, man-cave, etc. Objects themselves do not create the metaverse, they merely populate it. To create the metaverse itself – the background for the foreground of objects created in Dreamfusion – would take another tool.

That tool dropped earlier this year. Text2Room translates a text prompt into a 3D space. For example, "a living room with lots of bookshelves, couches and small tables" generates exactly the kind of cosy and inviting domestic space those words conjure in the imagination. The combination of Dreamfusion and Text2Room means that an average person, with average skills in English, can craft exactly the metaverse – a space plus the objects within that space – to meet their needs.

We used predictive text in the 1990s to save us a few button presses when spelling out words. What's going on in ChatGPT is not fundamentally different

So diffusers have solved the content problem for the metaverse, making the metaverse much more accessible – but that still doesn't provide a reason to use it, beyond the desire to create "a room of one's own".

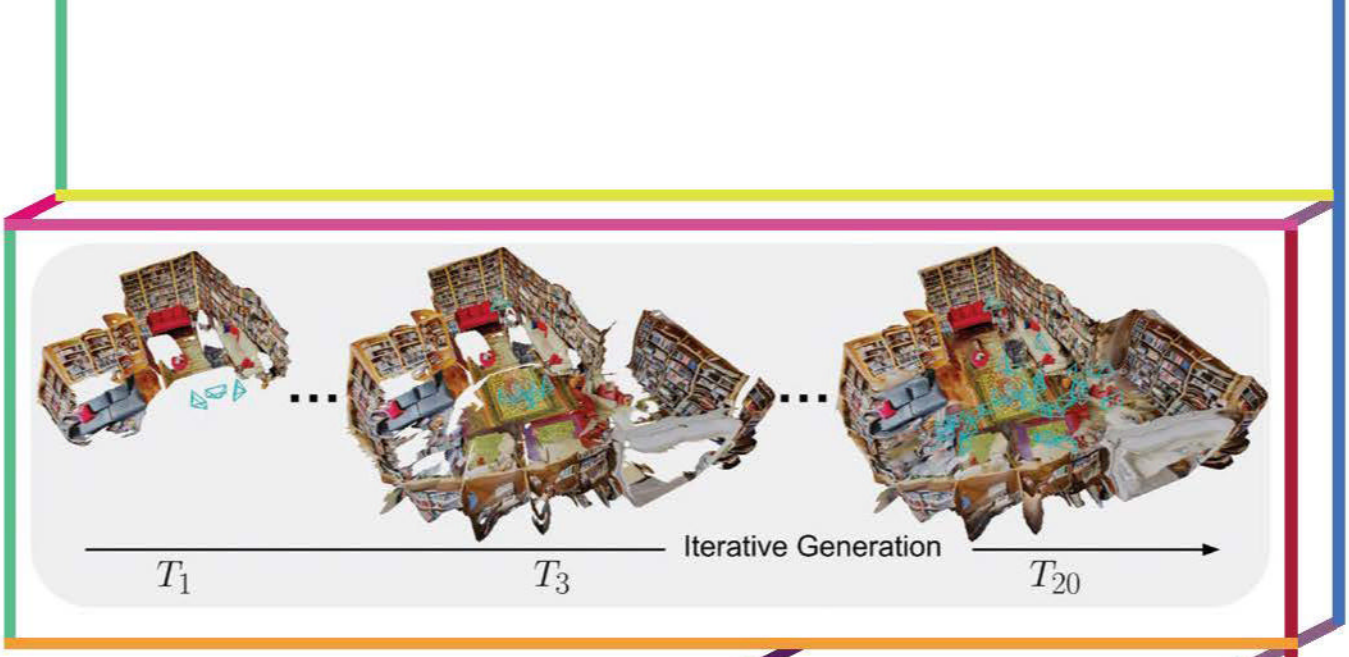
Homework helpers and their agents

Between the releases of Dreamfusion and Text2Room, another massive revolution in artificial intelligence had its public kickoff when, at the end of November 2022, OpenAI unveiled ChatGPT, its AI-powered "chatbot".

Trained across at least 400 billion "tokens" – think of them as syllables – gathered during a Common Crawl that hoovered up most of the publicly available text on the Internet, ChatGPT has the ability to provide "completions" to nearly any prompt put to it. (Common Crawl is a US not-for-profit that provides cost-free copies of the internet for research and analysis.)

It's best to think of these completions as a scaled-up version of the same sort of predictive text we were using on our mobiles long before they became "smart". We used predictive text in the 1990s to save us a few button presses when spelling out words in a text message. What's going on

LEFT, FROM TOP: DALL-E 2; MIDJOURNEY.



in ChatGPT is not fundamentally different, though it uses the very latest artificial intelligence "attention" techniques to provide completions both substantially longer, and (fortunately) meaningful across their length. (That's quite a trick. The next time you send a text message, try repeatedly selecting the next word recommended by your smartphone – it soon descends into nonsense.)

Unless you've been living under a rock, you know that ChatGPT quickly became one of the biggest apps in internet history, getting to 100 million users in its first 60 days of release – and causing a fair bit of disruption to both teaching and office work as users ferreted out how to craft prompts that could shoulder a lot of their boring tasks – and homework!

In February 2023, when OpenAI upgraded ChatGPT with GPT-4 – its latest and greatest AI model, with undisclosed but self-evidently far greater levels of training – it became clear that ChatGPT had enough capacity to be put to work in a range of sophisticated tasks, such as working its way methodically from a text prompt toward the solution to a problem.

Just a fortnight after OpenAI made GPT-4 available to a restricted list of "beta testers", programmer and video game entrepreneur Toran Bruce Richards released Auto-GPT, an "autonomous agent" harnessing GPT-4 as a generalised problem solver. It's best to think of Auto-GPT as a private conversation with ChatGPT. To use Auto-GPT, you provide a text prompt that's a clerical or writing task you'd like Auto-GPT to perform. In consultation with GPT-4, Auto-GPT turns this task into a goal, then – again in consultation with GPT-4 – breaks that goal down into a series of steps. Finally, Auto-GPT breaks those steps down into a series of discrete actions (and yes, it does this too with the assistance of GPT-4), then performs each of these actions.

Text prompt: "A living room with lots of bookshelves, couches and small tables." Result: Text2Room creates 3D spaces through iterative generation (version 1, 3 and 20 shown above) with new viewpoints in blue. The final result uses multiple viewpoints to create the mesh, above at right.

That all sounds good, but what happens if the world doesn't work as GPT-4 imagines? What if Auto-GPT takes an action and it fails? Can it even know that it's failed? Here's where good old-fashioned computer science comes in, in the "reflect and act" (ReAct) loop. Every action is checked against its expected results – that's the reflection – and if those results don't meet expectation, the action is reworked (in consultation with GPT-4, naturally), and attempted again and again until it succeeds. Only then will Auto-GPT go to the next step.

Auto-GPT can be slow and bumbling (all while burning through expensive GPT-4 computer time), and sometimes it fails, but more often than not it succeeds in whatever task it has been assigned. These first-generation autonomous agents – Auto-GPT, AgentGPT, BabyAGI, and a growing list of others – point to a future for computing where we propose, via a text prompt, and they implement.

Autonomous agents can only be as powerful as the tools they command. Today that's largely

limited to Google searches – and, for the daring, the ability for an autonomous agent to write and execute programs on their own computer. (For this reason, most autonomous agents run in "containers" – sandboxes that keep them from wrecking other parts of the computer should they run amok.)

But here's where the real world starts to get interesting. Soon, we'll see autonomous agents equipped with a broad range of tools – and in particular, creative tools like Dreamfusion and Text2Room.

When that happens, it will be possible to prompt "create a hospital emergency department with a patient triage area, 20 beds, and a small surgical suite", then sit back as an autonomous agent figures out exactly what that ED should look like, what equipment it should have, where that equipment should be placed, and so forth, then feed all of this into tools that will generate the space of the ED and all of the objects within it.

Autonomous agents help us move from prompt to metaverse; but that metaverse lacks one important element: people. While it might be possible to find 40–50 individuals who could role-play their way around this generated ED, that's not going to be common – or cheap. Instead, we'll rely on another recent innovation in AI: "generative agents".

Why the artificial world will matter

In April 2023, a group of researchers at Stanford University and Google published a paper in which they detailed a town they called Smallville, which they populated – virtually – with 25 "personas". Fed into GPT-4 as prompts, each persona describes a person, their likes and dislikes, their home and work lives, their favourite and least favourite activities, and so on. This "biography" allows GPT-4 to generate synthetic behaviours for each persona. The researchers then wired all of these personas together so that they could freely interact with one another. Voila! Smallville had 25 "people" with their own interests, peccadilloes, and pursuits.

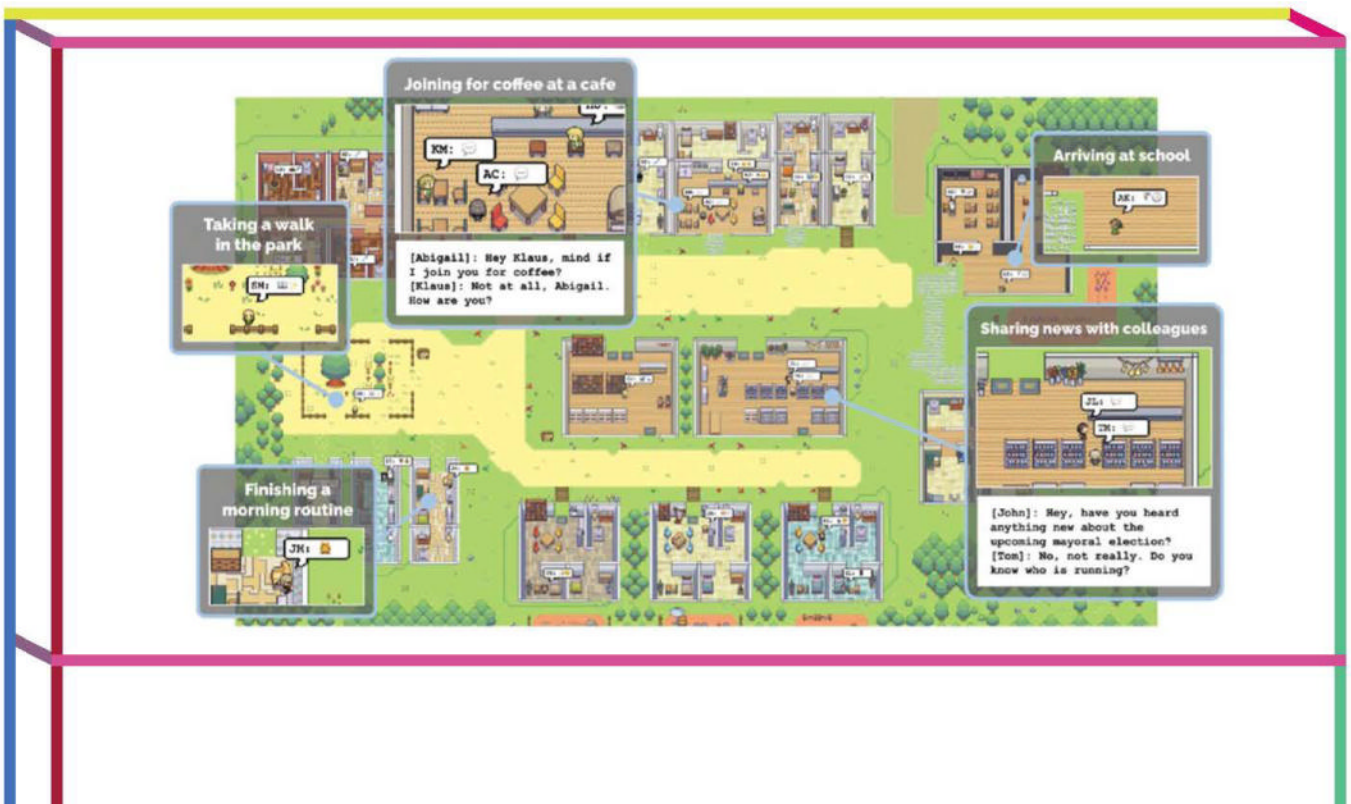
Researchers provided a goal to one of the Smallvillians: organise a party to celebrate Valentine's Day. Another persona volunteered to decorate the Smallville cafe for the event – because she intended to use the party to pursue a romantic interest. Party organisers sent out eight invites to the party. Five accepted. Three declined – because those Smallvillians had other things to do! (You also have to wonder about the other 15 Smallvillians who didn't receive an invite at all.)

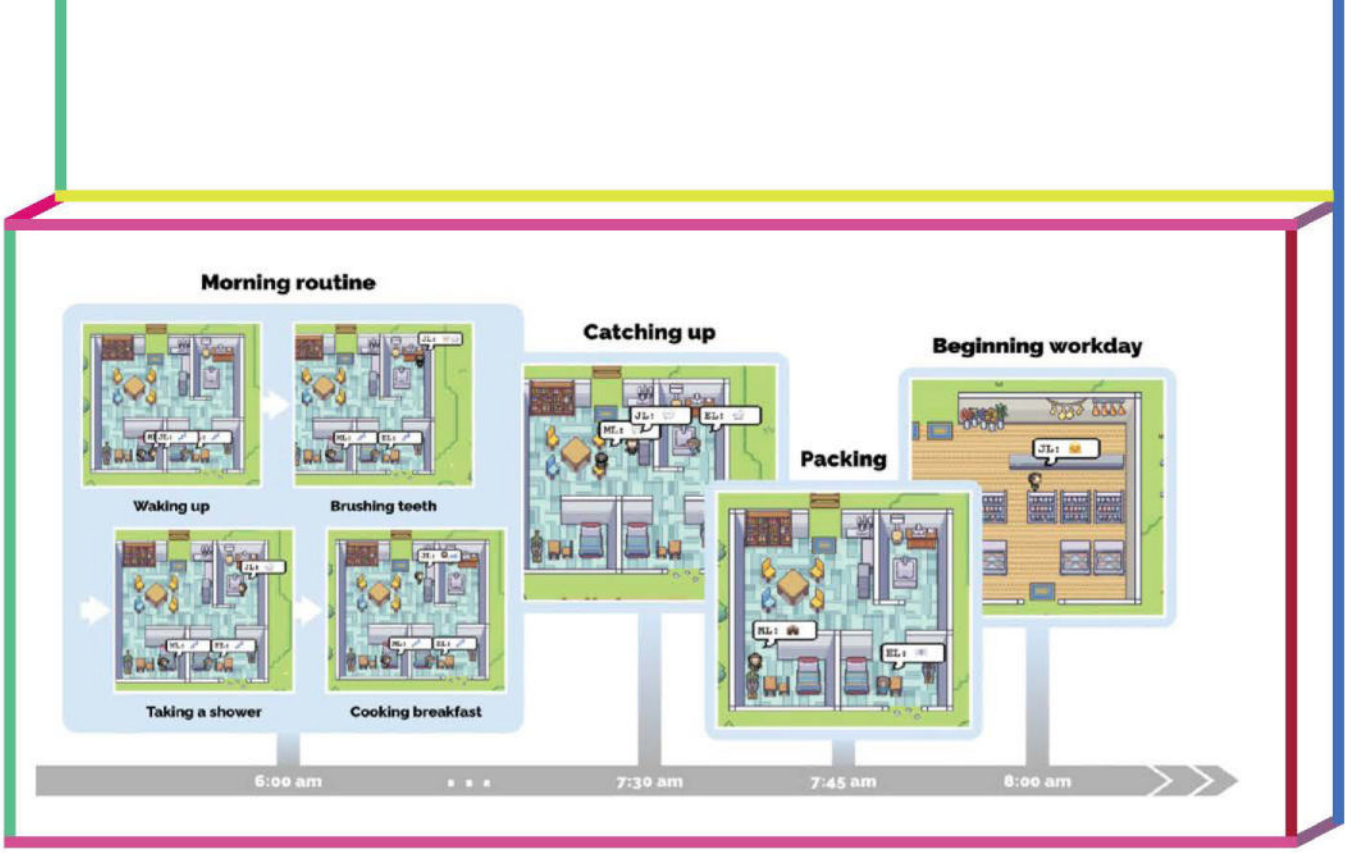
The research proved that GPT-4 could be used to create generative agents. All they needed to do was to interact with one another – the rest would take care of itself.

Long before the 200th issue of *Cosmos*, generative agents will be common. They'll likely show up first in video games – replacing those dumb-as-a-bag-of-rocks NPCs (non-player characters). But we'll really need them in our autonomous-agent-built simulations of scenarios such as that ED. Construct 40 personas – a combination of patients, nurses, doctors and anxious family members – drop them into the environment it created, and let them interact.

This isn't just a simulation for simulation's sake: it's a training tool. Drop a real nurse or doctor into this environment and they quickly learn how to operate within a variety of high-stress

Researchers created Smallville, and populated it – virtually – with 25 "personas" generated by GPT-4. Over time the characters developed relationships and behaviours, sharing news and organising group activities.





The morning routine (above) of Smallville resident John, who wakes each day at 6am, showers, eats breakfast and chats with his wife Mel before heading to work.

environments – capacities integral to patient care. Queensland Health recently spent a large amount of money to create a single such training simulation – with this new suite of tools, they can spin up as many as they need, on demand, each designed precisely to the trainee's requirements.

This is what I call the "syntheverse" – a concatenation of the latest AI tools, coming to the rescue of 30 years of metaverse failures. People will have a reason to go to the metaverse – to work, to learn, to play, and to explore.

Let's use architecture as an example. You have to produce a client brief for a new apartment block. Using the syntheverse, you build a walk-through 3D tour – that's easily done. You have to create a site plan; that's less easily done, because now you're bringing into play everything connected with actually building the building – marshalling resources and contractors and making a timeline. But once the how-to bit is conquered, the syntheverse will allow people to do planning at unheard-of scale. And at such a low cost! It'll be possible to spin up ideas at a rate of knots – whether or not they're actually useful.

The more that we rely on these kinds of simulations, the more we'll need experts who will be able to monitor their performance and ensure it's up to par

It's important to say that getting to this point won't be easy – and just as important to say it's not going to put everyone out of work. What we've learnt so far about generative AI is that its agents can run off the rails very quickly. They "hallucinate". They make mistakes – and don't know they're making mistakes. The more that we rely on these kinds of simulations, the more we'll need experts who will be able to monitor their performance and ensure it's up to par – before a simulation tool is handed to people who aren't expert. So in the mid-21st century, artificial intelligence will be increasing rather than decreasing our need for experts.

I've thought about this in terms of going back to where the spreadsheet was. A spreadsheet is the single most important application that's ever been written for a computer. If we didn't have VisiCalc there'd be no Apple, there'd be no IBM PC. We wouldn't have personal computers everywhere, which means there'd be no web. The ability to simulate numbers – which is fundamental to how we operate our civilisation now – is part of what the spreadsheet gave us. The syntheverse is going to be that, but much more fully realised. And just like the spreadsheet, the syntheverse will be everywhere in our world.

The syntheverse will push us into being better at what we do: more expert, so we can do more with our tools. Generative AI amplifies our creativity. How we direct that creativity remains in our control, today and into the decades to come.

MARK PESCE is a futurist based in Sydney. His last story for *Cosmos*, on nano, appeared in Issue 94.

Making the Mudcrab

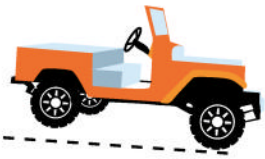
A pair of Darwin engineers, their mates and a small army of unpaid helpers have just pulled off a nifty and adventurous technological feat – in a decades-old car fitted with off-the-shelf and budget custom components. Text and photography by **David Hancock**.

Caption

Australia's Top End has always been something of a haven for eccentrics and their activities. Perfect example: Darwin's Rocksitters Club, a Saturday evening tradition of nearly five decades' standing to which people go for a beer to watch the weather turn spectacular. The Darwin ice hockey club reckons they're world champs because no other team has ever taken up the challenge to play them.

Darwin's a city with one of the highest per-capita aggregations of four-wheel-drive vehicles, and Darwinites particularly enjoy anything to do with cars. In 1983, the city went troppo when a group of mates decided to drive their Toyota Landcruiser across the harbour, under water. The 'cruiser – complete with 60-metre-long snorkel – made it half way before its starter motor flooded and couldn't get going after stalling.

A makeshift hood ornament (opposite) takes pride of place as Finn Davy (in driver's seat) and Glen Summers prepare the Mudcrab for immersion. The vehicle underwent extensive testing at Oceantec (above left), in Darwin, including (below) being submerged in a tank to ensure its electrical systems (above right) were watertight.



Roll on four decades to July this year, and another generation of Darwin characters and their mates successfully completed the same harbour crossing, using a similar kind of vehicle – a 40 series SWB Landcruiser, dubbed the 'Mudcrab' – only this time, the vehicle had an electric motor and batteries.

Incredibly, the group of young engineers and their mates who pulled off the feat – assisted by a team of commercial and saturation divers and a network of volunteers – did so on a limited budget with components ranging from off-the-shelf to custom designed and fabricated.

Darwin-born engineers Glen Summers and Finn Davy, and filmmaker Tom Lawrence, spent 14 months on the project, which set a number of world records, including the longest distance travelled and maximum time underwater by a car.

Much of Summers' education was spent working on solar cars – firstly for his school in Darwin, and then for the University of NSW. Solar and electric energy became his passion and, today, he works in that field in Melbourne.

For many Darwin kids with an interest in engineering and adventure, like Summers, Davy and Lawrence, the 1983 harbour crossing attempt became folklore and – to them – more than just another crazy Top End stunt.

"When I first got the call from Tom Lawrence, last year, I called one of my friends in Silicon Valley, Scott McDaid, who is an underwater ROV [remote operating vehicle] expert to see if it was possible," Summers says. "I knew how to build an electric car but wanted to know if it was possible to make it 'underwater-proof'."

Summers found that waterproofing ROVs is commonplace. The biggest challenge is to make them and their components compatible with external water pressure.

"The motor is from the world of EV conversion equipment; the kind of gear you buy to convert your car into an electric vehicle," Summers says. "That made a lot of sense for us because the

powers are matched and they are very easy to interface and control. We didn't have the time to build the motor and controller ourselves and we would have needed a team of specialist engineers.

"On the other hand, the supply chain of that [EV] world is as lot thinner than we thought. With the motor and controller, there was only one in Australia that I hunted down out of Castlemaine, a hot rod town in Victoria."

The underwater vehicle would reach a maximum depth of 30 metres.

The blueprint was to encase everything in silicon oil and keep custom-built aluminium waterproof containers of electrical and mechanical components at a slightly higher pressure inside than out. "The pressure compensation system operates by always keeping a small positive pressure inside the containers relative to outside the containers, to keep the water out," Summers says.

He worked with Australian friends based in Silicon Valley – Matt Godfrey and Alex Boulgakov – who designed electronic circuit boards specifically for the project. Finn Davy built a pressure chamber where all components were thoroughly tested.

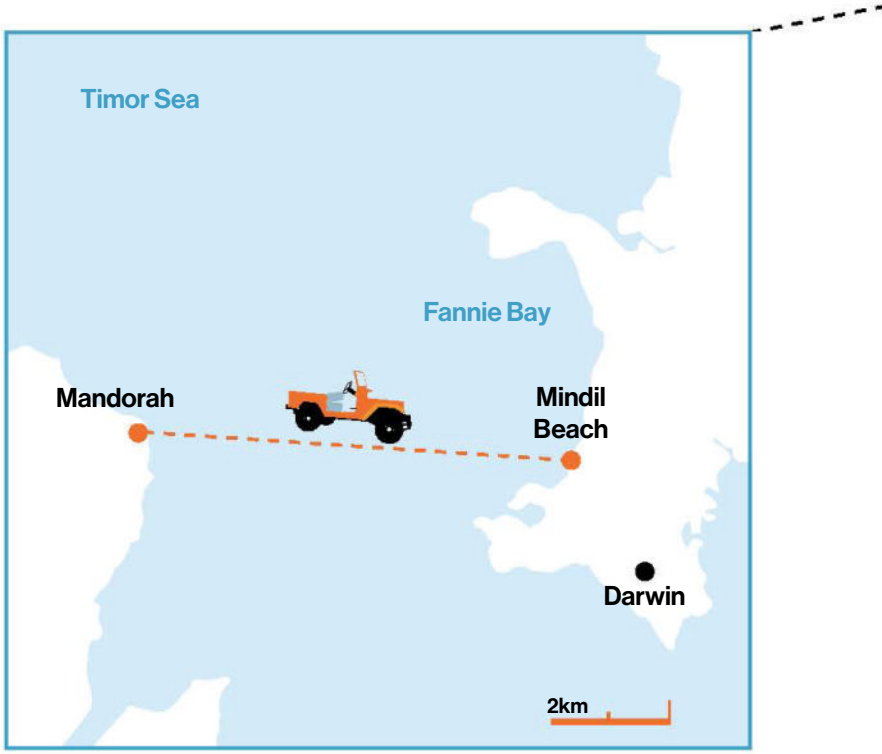
"We needed some medium to fill the containers that held the motor, controller and battery," Summers says. "It needed to be inert electrically and it couldn't be air because of the external pressure. The silicon oil gave us a completely inert environment that was clear so we could see through it to check the components.

"We originally wanted to have cool LED lights running through the containers – can you imagine how awesome it would have been having a blue glow in the motor and the cable connecting the battery? But that was just aesthetics we didn't have time for."

The team kept the project as simple as possible – hence the 40 series 'cruiser, which was easy to convert, and the basic electric motor. But the underwater controls, for the divers, were a challenge. They solved it by making a circuit board containing piezo switches to turn the controls on and off. A piezo switch generates a pulse of electricity that opens and closes the underlying circuit. They bought the Israeli-made switches from an underwater tech shop, in Perth.

Summers says the team made an underwater throttle using a Hall effect sensor sourced from a hobby electronics retailer in Hobart; the assembly was 3D printed and encased in epoxy. "The physical containers for the battery, motor controller and engine were important," Summers says. "We had to keep the ocean out – and the pressure in."

Crowds gathered (above left) on the beach at Mandorah, about 6km west of Darwin, to witness the Mudcrab begin its epic trip. The vehicle's first and only test drive (above right) was at Casuarina Beach, north of the city, when the team drove the Mudcrab for several hours at depths of up to 4m. It performed perfectly.



Luke Purdy, Travis Lia and Finn Davy custom designed the three main silicon oil boxes, including the interface between the electric motor and the spinning connection to the gearbox. They waterproofed the shaft and spinning axis with three rotational seals and a grease barrier, estimating it was the area with the highest risk of taking in water.

"Days after the crossing we expected some water to have come in but there was none in the silicon oil," Summers says. "The entire system worked really well at staying completely waterproof. The hardest area to waterproof was around the shaft coupler. We packed the front and rear diffs [differentials], and transmission, with food-grade grease, which is environmentally friendly."

"It really became like a classic 4WD trek; the wheels would spin in the mud, the car would sink down [...] the driver would have to stop and reverse..."

Tyres were another special DIY fix: they were filled with water. "If they had been filled with air, they would have been crushed at 30 metres," Summers says. "They were very heavy – being filled with water – and we feared the wheels might not grab the tyres, so we glued them to the rims.

"When we had traction, the car ran very well and we had a very efficient turnaround of divers. We were optimistic we could drive the seven kilometres across the harbour in three hours but it ultimately took 12 because the car bogged in areas of soft mud.

"It really became like a classic 4WD trek: the wheels would spin in the mud, the car would sink down to its axles, the driver – who was attached by umbilical cord to a dive boat – would have to stop and reverse and then go forward or find another route. In one patch they used air bags to lift the vehicle. All that with 30 divers changing out every 15 to 30 minutes so they didn't have to decompress."

In brighter waters near the surface (above), visibility extended for up to 5m, but as the vehicle went deeper during the record attempt the crew was engulfed in muddy water that reduced their visibility to less than a metre. The Mudcrab was equipped with basic sonar and its harbour-crossing route (opposite below) was charted and directed from a support vessel on the surface. Scuba-equipped drivers rotated every 15–30 minutes so they didn't have to decompress.

Due to federal government requirements, the vehicle also had to be lifted over an underwater gas pipeline than runs from the Timor Sea to processing plants deep in Darwin Harbour.

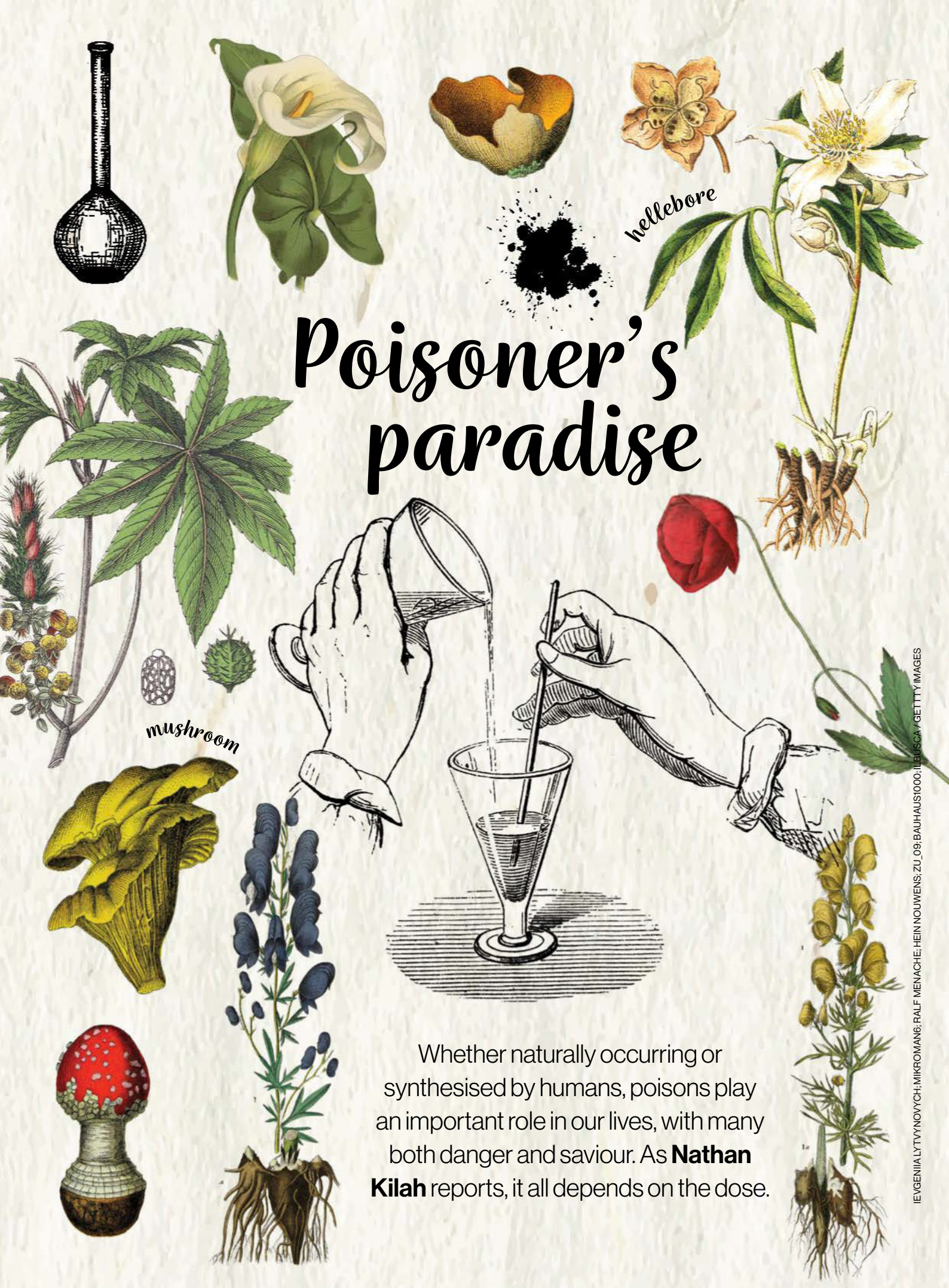
Summers says there were some "amazing flukes" that kept the project going for 14 months, and success was down to the energy of the more than 100 people who contributed their time and skills free of charge.

After the Mudcrab crawled ashore at Mindil Beach in the pitch dark several hours later than expected, Davy said the project was a testament to what can be achieved by a bunch of ordinary people in a backyard or shed without being heavily funded.

"We have also proved the robustness of the electrical systems," he says.

"You can put them under a lot of pressure that they were totally not designed for and they operate as they should."

DAVID HANCOCK is based in Darwin. His article about Naworo was last issue's cover.



Poisoner's paradise

Whether naturally occurring or synthesised by humans, poisons play an important role in our lives, with many both danger and saviour. As **Nathan Kilah** reports, it all depends on the dose.

mushroom

Make no mistake. Hundreds of people and animals were killed to bring you this story. Poisons are all around us, as are people with motives to use them for their hostile and cruel intentions.

At the molecular level, poisons are chemicals typically with very specific functions. In my professional life as a chemist I've handled many, including well-known substances like cyanide, carbon monoxide and mercury; war gases such as chlorine and arsenicals; and toxic alkaloids such as strychnine and nicotine. Many of these chemicals are reactive, which makes them useful tools in producing new molecules. Others have special properties that help in isolating other desirable molecules. Working with these chemicals takes preparation, good laboratory engineering, imaginative risk management (nerve!), and genuine humility and respect for the dangers in front of you.

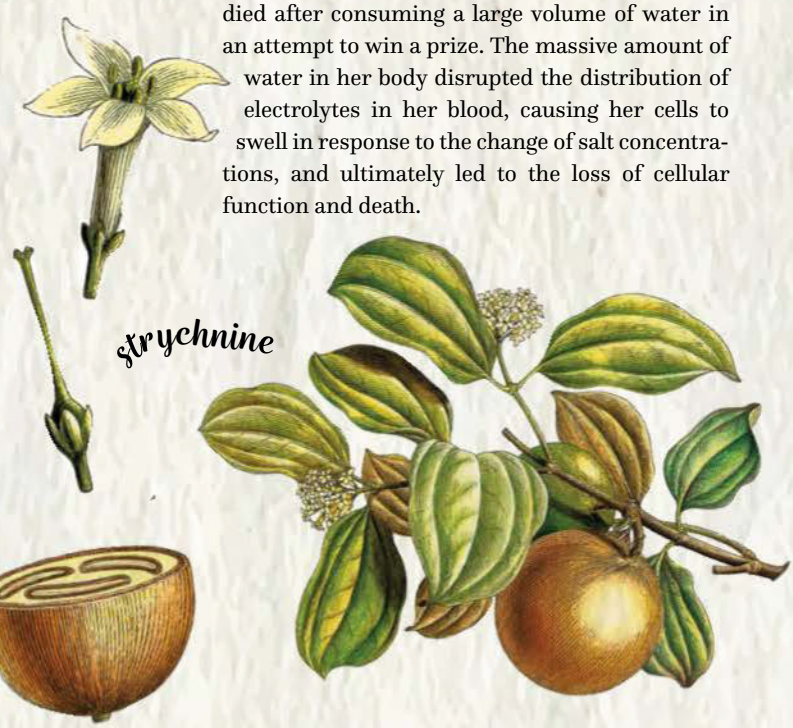
Because when you entwine that chemistry above a certain dose with the chemistry of an unsuspecting victim, things start to go wrong very quickly.

Whether a poison is ingested, inhaled, absorbed or injected, the end result is often the same. Death. Untimely, undignified, often painful and frequently gory. But what makes a poison a poison? Where do poisons come from, and how are they useful (other than for poisoning)?

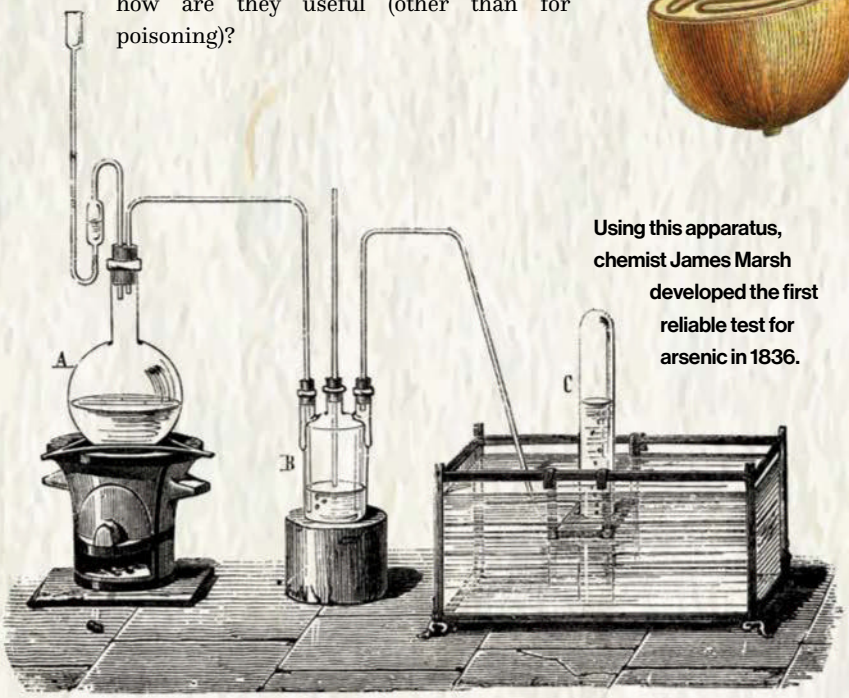
What is a poison?

On a biochemical level, a poison is a disrupter. The poison may disrupt the packaging of your cells, causing them to leak and lose function, or it may disrupt the information flow of your nervous system, leaving normally rapid-firing neurons perpetually on or off.

The common factor is that above a certain concentration, any chemical can be deadly. Even a molecule considered benign, such as water, can be a killer. In 2007 a radio game-show contestant died after consuming a large volume of water in an attempt to win a prize. The massive amount of water in her body disrupted the distribution of electrolytes in her blood, causing her cells to swell in response to the change of salt concentrations, and ultimately led to the loss of cellular function and death.



strychnine



Using this apparatus, chemist James Marsh developed the first reliable test for arsenic in 1836.

Flora and fauna

The majority of well-known poisons come from nature. Your average garden is a poisoner's paradise, with lilies, hellebores, beans, mushrooms and more all capable of delivering death. Our ancestors worked out which plants and fungi could be eaten through the application of an early scientific method, and the safety net of a big enough tribe to survive mistakes.

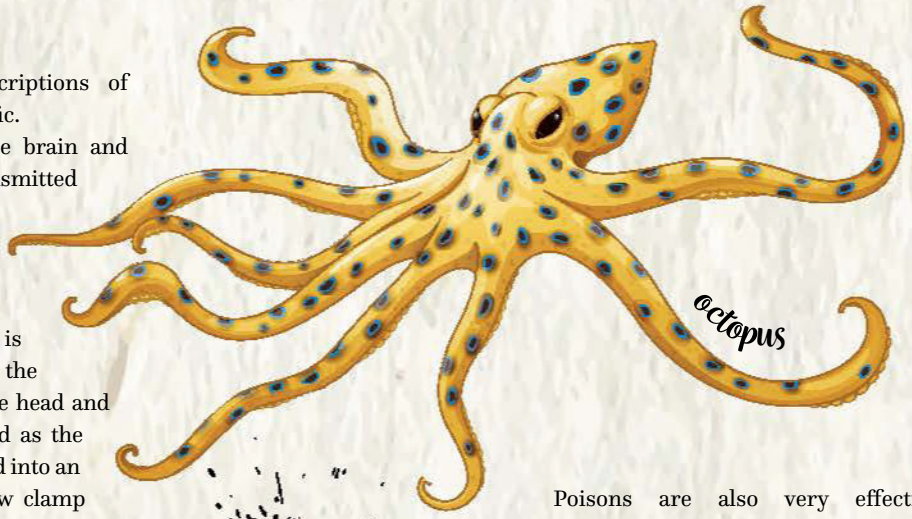
Many plants have evolved poisonous defences to avoid being eaten. This is often in the leaves but is frequently concentrated in the fruits and seeds as a way to ensure subsequent generations.

The seeds of the strychnine tree (*Strychnos nux-vomica*) are particularly well known for their

poisonous potential. Detailed descriptions of strychnine poisoning are truly horrific.

Ingested strychnine binds to the brain and nervous system, keeping neurotransmitted messages turned on while enhancing the sensory systems of the body. This heightened state makes the body very sensitive to stimulation, and the reaction to stimulation is muscle convulsions. These contort the entire body, so that only the tip of the head and the tip of the heels touch the ground as the torso and legs are tensed into an arch. Fists and jaw clamp shut, the mouth pulls into a grimace and the diaphragm locks tight for minutes at a time. If the poisoned individual lives through this suffocating period, they may restart the cycle, fully conscious, their exhausted body strained by further convulsions. Depending on the dose and the fortitude of the victim, the whole-body contractions may continue for a number of cycles before agonising death.

Despite strychnine's well-deserved reputation, it remains part of Chinese and Ayurvedic traditional medical practices, albeit in very controlled doses, used to treat a range of conditions including diarrhoea, inflammation, paralysis, rheumatism and sexual function.



What do all these critters have in common? You guessed it – they produce toxic chemicals capable of killing you.

Poisons are also very effectively employed across the domains of animal life, with frogs, snakes, octopuses and many others capable of causing death. A small number of frogs of the genus *Phyllobates* produce batrachotoxins, which have been deployed in poison blow darts used in traditional hunting practices in Latin America, alongside the more common plant-based curare. These poisons function within the bloodstream, so prey killed by this method can be eaten without causing any ill effect.

More intentional poisoning involving members of the animal kingdom used extracts of blister beetles (family *Meloidae*). The active agent cantharidin, which the beetles use to protect their developing eggs, causes blisters and chemical burns. If taken internally, cantharidin can produce blisters that can cause bleeding, followed by vomiting and diarrhoea, and ultimately death.

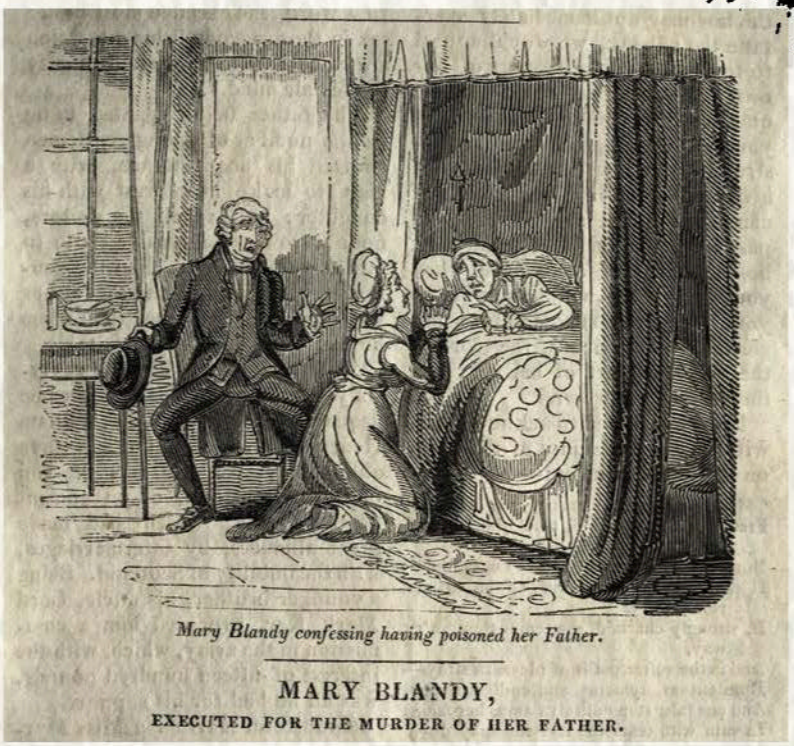
The first test for cantharidin poisoning was grim. The content of the deceased's stomach was concentrated, then placed on healthy, living skin with a bandage. If blisters formed underneath the bandage, then cantharidin was the poison. Another more obvious sign of cantharidin poisoning was priapism – a prolonged, rigid erection – that persisted after death.

This final display also highlights the blister beetle *Lytta vesicatoria*'s better-known name of "Spanish fly", and its use in aphrodisiac potions

RAT POISONS

You will no longer find arsenic, thallium or strychnine rat poisons at your local home and garden centre. It's preferable to choose "first-generation" poisons like warfarin, coumatetralyl or salt, as these are safer for birds of prey, which often eat sick rats. Second-generation anticoagulant rodenticides such as brodifacoum, bromadiolone and difenacoum can also kill raptors. An even better option for home is a poison-free trap.

L FEDDES; BLUERINGMEDIA; CLU; TIGERSTRAWBERRY; NASTASIC / GETTY IMAGES



Mary Blandy confessing having poisoned her Father.

MARY BLANDY,
EXECUTED FOR THE MURDER OF HER FATHER.

made from cantharidin. Aphrodisiac preparations are said to have led to many poisonings throughout history. The most famous case involved the French nobleman Marquis de Sade, who is said to have poisoned two prostitutes with cantharidin-laced sweets in 1772.

Poisonings don't always come packaged with a motive. Take, for example, the mass poisoning of French villagers by grains contaminated with the ergot fungus *Claviceops purpurea*.

This ergot fungus produces alkaloids that can cause hallucinations. The appearance of these hallucinations is so well-known that they have been called Saint Vitus' dance when accompanied by twitching, burning sensations and feelings of suffocation, and Saint Anthony's fire when the poisoned person appears to be demonically possessed or is behaving "like a witch". Ergot poisoning has been implicated in witch trials – it's posited that the erratic behaviour of a few poisoned individuals caused an irrational response in a larger group.

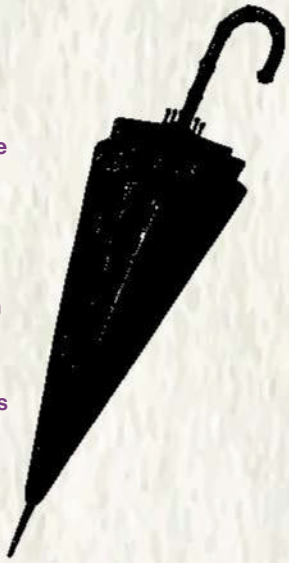
Ergot poisonings – also known as ergotoxicosis – can be widespread, as occurred in the French village of Pont-Saint-Esprit in 1951, when hundreds of people were poisoned by ergot through their local bakery. The effects on the body can be more severe. A related class of long-term ergot poisoning known as ergotism causes gangrene of the limbs as the toxin cuts off the blood supply. Plenty of fungal toxins may be present on mouldy food, so reconsider cutting visible mould off and eating the remainder – the threads of mycotoxin-producing mycelium may have travelled further than you realise.

> "Your average garden is a poisoner's paradise, with lilies, hellebores, beans, mushrooms and more all very capable of delivering death."

INDIGENOUS FISHING PRACTICES

Indigenous Australians used a highly effective method to catch fish. Crushed plant roots from legume species were added to waterways, where the active chemical rotenone stunned or killed the fish. This piscicide has also been used to rid waterways and lakes of invasive aquatic species. Rotenone is still widely available as a treatment for mites and lice in poultry.

SPY VS SPY I: RICIN IN SPY ASSASSINATION



An umbrella seems an unusual weapon, but in 1978 the tip of one was used to deliver a lethal dose of ricin to Bulgarian dissident writer Georgi Markov. This protein, also known as a lectin, is produced by the castor bean plant. The same plant is used to produce castor oil, but the chemical properties of the ricin means it does not get extracted into the oil. The castor bean isn't the only plant that produces lectins: four to five raw kidney beans contain enough for toxic effects.

Elemental poisons

There are other poisons from nature that require a bit more chemistry knowledge to obtain: those derived from minerals.

Arsenic has been known as a poison for centuries and kills by damaging cells and interfering with cellular respiration. Of note is the signature brew of the Italian professional poisoner, Guilia Tofana (died 1651). Her Acqua Tofana, thought to contain arsenic, lead and belladonna, was a tasteless liquid that could be added to a glass of wine or a meal.

It's claimed that as many as 600 women used this potion to kill their husbands.

DUNCAN1890; YURII SIDELNYKOV; CHANNARONGSDS / GETTY IMAGES

A single dose wasn't fatal, so as the killer nursed their ailing victim they continued dosing them with poison. This gradual progression towards death using Acqua Tofana highlights the challenge of separating poisoning from the symptoms of disease. Common signs of arsenic poisoning – such as vomiting, chills and fever – are consistent with many bacterial and viral infections, which were prevalent in the 17th century.

It was almost two centuries later, in the 1830s, that a reliable test for arsenic was developed by English chemist James Marsh. Motivated by having failed to prove the guilt of an arsenic poisoner (who later confessed to his crime), Marsh set out to construct a glass apparatus that could specifically establish the presence and quantity of arsenic.

His process – known as the Marsh test – was very successful and is considered to have deterred future deliberate poisonings with so-called "inheritance powders". Marsh's efforts represent one of the earliest techniques of modern chemical forensics.

Synthetic poisons

The arrival of modern chemical sciences made many of the old poisons less appealing for those with murderous intent, as restricted availability and ease of tracing meant the poisoner became much easier to identify.

But this hasn't stopped the development of countless poisons. From the gases used in trenches during the Great War to chemical agents that enabled the Holocaust, humans seem to have an endless capacity for ingenious chemical horrors.

Synthetic poisons are often chemical weapons developed by nation-states.

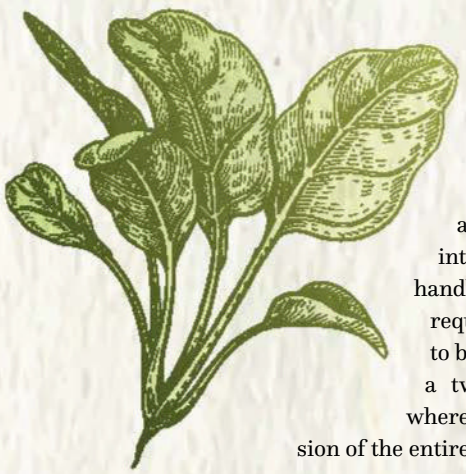
"Medicines are also potent poisons when taken at the wrong dose. Even commonplace paracetamol can be deadly."

The Chemical Weapons Convention currently has 193 member parties, and while some countries have been actively working to lower their stockpiles of chemical weapons, 15 states maintain declared chemical weapon production facilities. Certain countries have dipped into their military stockpiles for attacks, both foreign and domestic, as well as for more personalised targets.

In 2018 in Bristol, England, a synthetic poison of particular strength was deployed against former Russian/UK double agent Sergei Skripal. This "novichok" weapon (Russian for "newcomer") was developed after the nerve gases sarin and VX. These weapons share common chemistry as they are all organophosphate nerve agents. The novichoks are intended to be deadlier, but easier to handle. Some are binary weapons and require two components to be mixed to become active. This works well for a two-person assassination squad, where neither poisoner is in possession of the entire weapon.

POPEYE-FUEL POISONING

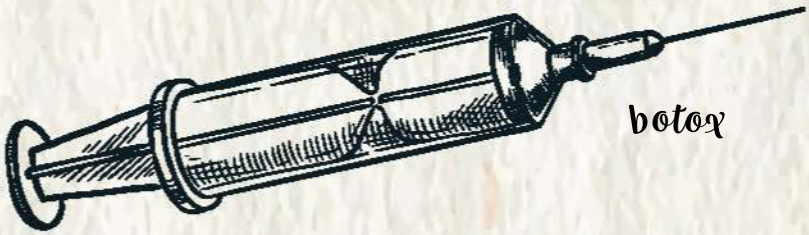
Unintentional poisonings are surprisingly common. In late 2022, over 200 people in Australia became ill after eating contaminated spinach leaves grown at a horticultural farm in Victoria. The source of the contamination was the plant *Datura stramonium*, also known as the thornapple, which was inadvertently grown, picked, packaged, sold and then eaten by unsuspecting consumers. At least one person was hospitalised, but fortunately, there were no deaths.



ILBUSCA; MARINAVORONTSOVA / GETTY IMAGES

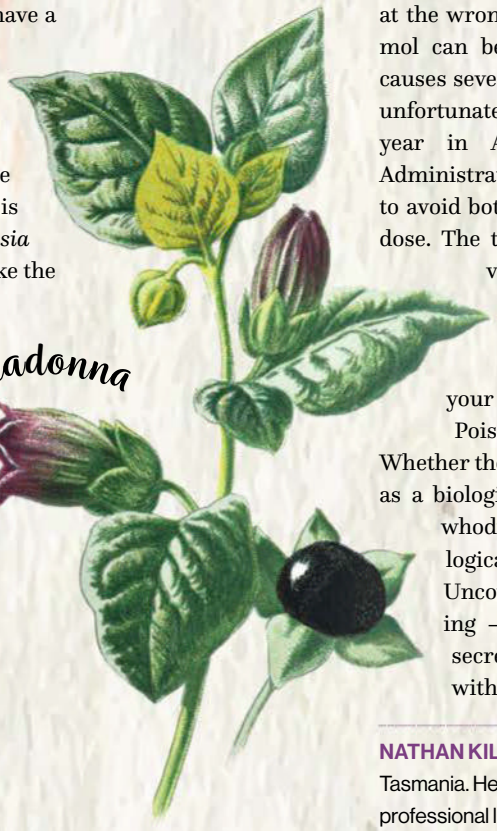
SPY VS SPY II: ENHANCED ELEMENTAL POISON

A highly specialised elemental poisoning occurred in 2006, when former Russian spy Alexander Litvinenko drank a cup of tea laced with polonium-210. This synthetic radioisotope emits massive amounts of energy in the form of alpha particles. The ingested polonium caused massive internal radiation damage, but did not penetrate outside of the body, which made detection difficult. The assassins were not particularly cautious with their highly potent polonium-210, and left a trail of radioactive material all across London, on credit cards, towels, restaurant tables, light switches, and down the sink of their hotel bathroom.



Poisons as medicine

A number of poisons from nature have long histories of use in traditional medicine. In these cases, keeping the poison's dose quantity low can have a therapeutic rather than deadly effect. Atropine from the plant belladonna has been used as an antidote to organophosphate and nerve gas poisoning, and is also routinely used for dilating the pupils in eye exams. Hycoscine, also found in belladonna, is extracted from the Australian plant *Duboisia myoporoides* and chemically modified to make the drug hyoscine butylbromide, often used in the treatment of irritable bowel syndrome, among other ailments.



The highly potent botulism toxin, produced by the bacterium *Clostridium botulinum*, causes paralysis and damage to the nervous system. Remarkably, this property has been used for a range of cosmetic procedures. Botox treatments have found application in treating migraines, overactive bladder and even in the treatment of rare gastrointestinal issues preventing patients from burping.

Medicines are also potent poisons when taken at the wrong dose. Even commonplace paracetamol can be deadly. This abundant medication causes severe liver damage when taken in excess, unfortunately resulting in around 50 deaths per year in Australia. The Therapeutic Goods Administration has moved to lower the pack sizes to avoid both intentional and unintentional overdose. The therapeutic range of pharmaceuticals vary widely, and one can easily enter dangerous levels if the instructions aren't carefully followed. So make sure you follow the dose directed by your doctor or pharmacist.

Poisons appear formidable and enigmatic. Whether they are deployed as a cowardly weapon, as a biological defence, as a plot device for the whodunnit writer, or as a safe pharmacological dose, they demand our respect. Uncovering their nature is endlessly alluring – as the true antidote is often not a secret potion, but the chemistry that lies within.

NATHAN KILAH is a senior lecturer at the University of Tasmania. He's handled many highly toxic poisons in his professional life and lives to tell their tales.

WHERE IN THE COSMOS?

Send us a pic of where you're reading *Cosmos* to win a limited edition notebook.

North meets south

This issue's Where in the Cosmos comes from one of the most exciting science projects on the planet – the Svalbard Global Seed Vault. Jeff sent us the picture from Longyearbyen, the world's northernmost town at a latitude of 78°. Philosophically and literally, this might be the coolest shot yet.
Thanks, Jeff! We'd love to see where you're reading: send us your shot at contribute@cosmosmagazine.com.

GUESS WHO?

Question
Whose Law? Decode where o = □

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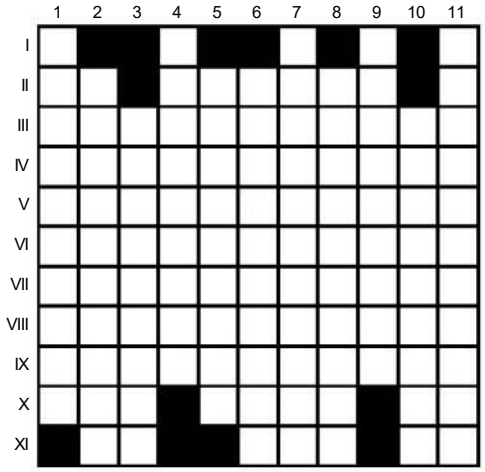
Hint: He discovered that water was made up of two parts hydrogen and one part oxygen.

MIND GAMES

NO.26

Who Said?

"What you do makes a difference, and you have to decide what kind of difference you want to make." (4,7)



Instructions

Answers to each of the clues in columns 1 to 11. Row IV reveals the answer.

Clues and columns

1 What is the curve described by a projectile in its flight? (10)
2 Who, with Putman, in 1958 published 'Unity of Science as a Working Hypothesis'? (9)
3 Whose five principles of architecture laid the foundation for what became the Bauhaus Movement in Germany and the International Style in the US? (2,9)
4 North of the Nullarbor Plains and deriving its name from an Aboriginal word for 'thunder', where did the British conduct atomic weapon testing in 1956? (9)
5 What is the line on a weather map connecting points having equal temperature variations? (11)
6 In the constellation Taurus, what remnant of a supernova was first observed in 1054? (4,6)
7 What is an effective procedure for solving a maths problem in a finite number of steps? (9)
8 Native to Australia and New Guinea what is the common name for the kingfisher of the genus *Dacelo*? (10)
9 Which instrument, carried aloft by a balloon, is designed to send back atmospheric information through a small radio transmitter? (10)
10 What law, named after a Dutch mathematician, states that when a ray of light is refracted at a surface separating two media, the sine of the angle of refraction to the sine of the angle of incidence is a constant? (6,3)
9 Which epoch, in the geologic timescale, extends from 5.333 million to 2.58 million years BP? (9)

COSMOS CODEWORD

NO.26

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, 'A' might be 6 and 'G' might be 23 .

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

4	4	12	21	22	4	12	26	■	24 P	4	2	1	14	21
1	■	14	■	2	■	14	■	24	■	11	■	7	■	6
7	4	3	26	20	14	21	■	4	11	11	6	12	15	1
14	■	14	■	17	■	■	■	9	■	20	■	6	■	24
12	14	1	14	4	12	3	13	■	1	6	15	24	20	14
23	■	1	■	12	■	23	■	11	■	3	■	■	■	20
6	12	6	1	■	4	3	23	2	1	7	6	3	1	■
21	■	23	■	25	■	3	■	15	■	■	■	13	■	17
■	6	8 N	5	2	12	18	■	6	8	6	7	6	4	20 L
6	■	■	■	4	■	10	■	17	■	12	■	8	■	4
15	23	2	20	21	18	■	19	4	3	26	9	4	12	21
24	■	7	■	12	■	16	■	7	■	1	■	■	■	6
4	22	14	12	4	17	14	■	14	24	23	3	13	■	23
6	■	12	■	8	■	12	■	■	■	15	■	4	■	20
12	14	6	8	7	12	23	21	2	3	14	■	1	26	6

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

ALL PUZZLES DESIGNED AND COMPILED BY SNODGER.COM.AU

IT FIGURES

NO.26

	1	2	3	4
A				
B				
C				
D				

Instructions

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

Level 1 – Chief Scientist

1. The first two numbers in each row add to the same as the two last.
2. Column three has the greatest number of primes.
3. Row C adds to 26.
4. The row which contains three square numbers is directly above the one made up entirely of multiples of 3.
5. Both diagonals contain only even numbers but only the upward sloping diagonal creates a consecutive descending pattern.

Level 2 – Senior Analyst

6. The largest number is in a corner.
7. There are two multiples of 7 in the bottom row.

Level 3 – Lab Assistant

8. The product of the first two numbers in Row D is 70.

SOLUTIONS: COSMOS 99

CODEWORD

P	A	N	D	E	M	I	C	■	A	S	S	I	Z	E
E	■	A	■	N	■	N	■	J	■	A	■	N	■	X
R	E	N	A	M	E	D	■	O	S	M	O	T	I	C
S	■	O	■	E	■	U	■	J	■	E	■	R	■	E
P	U	M	P	S	■	S	T	O	R	Y	L	I	N	E
I	■	E	■	H	■	T	■	B	■	■	■	N	■	D
R	A	T	E	■	B	R	E	A	K	F	A	S	T	■
E	■	R	■	Q	■	Y	■	■	■	O	■	I	■	I
■	F	E	M	U	R	■	O	V	E	R	A	C	T	S
C	■	■	■	I	■	M	■	A	■	T	■	■	■	O
H	Y	P	O	X	I	A	■	C	O	H	A	B	I	T
A	■	H	■	O	■	G	■	A	■	W	■	O	■	O
R	E	A	T	T	E	M	P	T	■	I	O	N	■	P
G	■	S	■	I	■	A	■	E	■	T	■	U	■	I
E	X	E	R	C	I	S	E	■	P	H	A	S	I	C

1 O	2 F	3 E	4 M	5 B	6 K	7 V	8 T	9 I	10 Y	11 D	12 A	13 W
14 X	15 C	16 J	17 Z	18 R	19 P	20 U	21 L	22 H	23 G	24 D	25 N	26 S

IT FIGURES

13	5	15	10
11	2	6	16
9	1	3	8
7	4	12	14

WHO SAID?

Anaxagoras

A Pre-Socratic Greek philosopher, Anaxagoras deduced a correct explanation for eclipses, and introduced the concept of the "Cosmic Mind".

A	■	■	T	■	E	■	G	S
R	B	D	H	■	P	B	C	I	E
M	E	I	I	S	I	O	I	G	I
A	N	A	X	A	G	O	R	A	S
D	L	G	O	P	L	L	R	H	M
I	E	R	T	P	O	E	H	E	O
L	X	A	R	H	T	A	O	R	L
L	C	P	O	I	T	N	S	T	O
O	E	H	P	R	A	■	I	Z	G
■	N	■	Y	E	L	■	S	■	Y

WHOSE LAW? ANSWER:

Most metals require 6.2 calories of heat to raise the temperature of one gram-atomic mass of metal by one degree Celsius. *Dulong-Petit Law*

The Green Chemists

Faulks, Gardner, Mastroyannis

Tessa Faulks, Zoe Gardner and Adele Mastroyannis are equally comfortable in a research lab or a middle school classroom – provided they're doing green chemistry in either venue.

They're all completing PhDs through the ARC Training Centre for Green Chemistry in Manufacturing – Faulks is at Monash University, while Gardner and Mastroyannis are at Flinders University.

"Everyone was quite passionate about motivating and inspiring younger people, maybe because that's where our inspiration came from," says Faulks.

Outreach is one of the Centre's requirements, and these three have been part of a team making green chemistry-themed activities for students in Years 6-9 – in between their own research projects on fertiliser coatings (Faulks), seaweed biorefining (Mastroyannis) and breaking down waste chemicals (Gardner).

Gardner says that green chemistry's positive outlook is a major drawcard. "Climate change is such a massive, massive issue, and a lot of kids these days are really switched on to that. It can be a little bit overwhelming," she says.

"Green chemistry provides an avenue of hope: there's actually something we can do about this. And it's exciting. That optimism is what drew me drew me to the area."

Mastroyannis, who has worked as a high school teacher, wants to bridge the gap between the (often dry) chemistry curriculum and students' real lives.

"We just have such a huge vision," she says. "My dream is to have green chemistry education really roll out within the curriculum [...] We're so far away from it, but I feel like we're also so close at the same time."

READ ABOUT CHEMISTS' CLEAN AND GREEN AMBITIONS ON PAGE 52.

From top: Tessa Faulks, Zoe Gardner and Adele Mastroyannis. Left: Mastroyannis delivers an outreach class for high school students.

> Green chemistry provides an avenue of hope: there's actually something we can do about this.

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